NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

THE IMPACTS OF CLIMATE VARIATIONS ON MILITARY OPERATIONS IN THE HORN OF AFRICA

by

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March 2006

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REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202i8-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.			
1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** March 2006	**3. REPORT TYPE AND DATES COVERED** Master's Thesis	
4. TITLE AND SUBTITLE: The Impacts of Climate Variations on Military Operations in the Horn of Africa			**5. FUNDING NUMBERS**
6. AUTHOR(S) Mark R. LaJoie			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited			**12b. DISTRIBUTION CODE**

13. ABSTRACT (maximum 200 words)

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14. SUBJECT TERMS Horn of Africa, El Nino, La Nina, Indian Ocean Zonal Mode, Long Term Mean, Climatology, Climate Variation, Climate Anomaly, Precipitation, Moisture Transport, Smart Climatology, Climatological Support, Military Operation, Military Planning, Warfighter Impact			**15. NUMBER OF PAGES** 153
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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THE IMPACTS OF CLIMATE VARIATIONS ON MILITARY OPERATIONS IN THE HORN OF AFRICA

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Submitted in partial fulfillment of the
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MASTER OF SCIENCE IN METEOROLOGY

from the

NAVAL POSTGRADUATE SCHOOL
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ABSTRACT

Department of Defense (DoD) climatology products rely mainly on long term means (LTMs) of climate system variables. In this research project, we have demonstrated that climatologies based on LTMs can be substantially improved using modern data and methods, especially by accounting for climate variations. We analyzed, and identified mechanisms for, enhanced (suppressed) autumn precipitation in the Horn of Africa (HOA) during El Nino (La Nina) events. El Nino (La Nina) precipitation anomalies were associated with anomalously warm (cool) western Indian Ocean sea surface temperatures, and with upper and lower tropospheric circulation anomalies that produced anomalously onshore (offshore) moisture transports in the HOA. These transport anomalies created anomalously strong (weak) precipitation over the HOA during El Nino (La Nina) events.

To improve climatological support for DoD operations, we developed and tested a six-step *smart climatology* process. We applied this process in the context of a notional, unclassified non-combatant evacuation operation (NEO) set in the HOA during autumn of an El Nino year. Using this process, we translated our scientific and operational findings into warfighter impacts. The smart climatology process we have developed is readily adaptable to other regions, seasons, climate variations, and military operations. We have provided a detailed description of our smart climatology process to facilitate its use by DoD agencies.

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LIST OF ACRONYMS

ACMES	-	Advanced Climate Modeling and Environmental Simulations
AFOG	-	Air Force Operations Group
AFW	-	Air Force Weather
AFWA	-	Air Force Weather Agency
AFCCC	-	Air Force Combat Climatology Center
AFWTL	-	Air Force Weather Technical Library
AO	-	Action Officer
AOR	-	Area of Responsibility
BOM	-	Australian Bureau of Meteorology
CIA	-	Central Intelligence Agency
CDC	-	NOAA Climate Diagnostics Center
CPC	-	NOAA Climate Prediction Center
CJTF-HOA	-	Combined Joint Task Force-Horn of Africa
CMOC	-	Civil-Military Operations Center
COADS	-	Coupled Ocean-Atmosphere Data Set
COMET	-	Cooperative Program for Operational Meteorology, Education and Training
CONPLAN	-	Contingency Plan
CONUS	-	Continental United States
CPC	-	Climate Prediction Center
DMI	-	Dipole Mode Index
DoD	-	Department of Defense
ECMWF	-	European Center for Medium-Range Weather Forecasting
EN	-	El Nino
ENLN	-	El Nino/La Nina
ENSO	-	El Nino/Southern Oscillation
FLENUMMETOCDET	-	Fleet Numerical Meteorology and Oceanography Detachment
GWOT	-	Global War on Terrorism
GRIB	-	Gridded Binary
HMMWV	-	Highly Mobile Multi-Wheeled Vehicle
HOA	-	Horn of Africa
HWC	-	Hadley-Walker Circulation

IO	-	Indian Ocean
IOD	-	Indian Ocean Dipole
IOZM	-	Indian Ocean Zonal Mode
IRI	-	International Research Institute for Climate and Society
ISR	-	Intelligence, Surveillance, and Reconnaissance
ISSCP	-	International Satellite Cloud Climatology Project
ITCZ	-	Inter-tropical Convergence Zone
JFACC	-	Joint Forces Air Component Commander
JMH	-	Joint METOC Handbook
JP 3-59	-	Joint Pub 3-59
LN	-	La Nina
LTM	-	Long Term Mean
MEI	-	Multi-variate ENSO Index
METOC	-	Meteorology and Oceanography
MIO	-	Maritime Intercept Operations
MJO	-	Madden-Julian Oscillation
NAO	-	North Atlantic Oscillation
NASA	-	National Aeronautics and Space Administration
NCAR	-	National Center for Atmospheric Research
NCEP	-	National Centers for Environmental Prediction
NCL	-	NCAR Command Language
NEO	-	Non-combatant Evacuation Operation
NEOPACK	-	Non-combatant Evacuation Operation Packet
NGO	-	Non-Governmental Organization
NOAA	-	National Oceanic and Atmospheric Administration
NPS	-	Naval Postgraduate School
NRL	-	Naval Research Laboratory
NWP	-	Numerical Weather Prediction
OLR	-	Outgoing Longwave Radiation
OCDS	-	Operational Climatic Data Summary
OWS	-	Operational Weather Squadron

PDO	-	Pacific Decadal Oscillation
PMEL	-	NOAA Pacific Marine Environmental Laboratory
ROE	-	Rules of Engagement
RSJ	-	Reverse Somali Jet
SH	-	Specific Humidity
SJ	-	Somali Jet
SMO	-	Senior METOC Officer
SOI	-	Southern Oscillation Index
SOF	-	Special Operations Forces
SOP	-	Standard Operating Procedure
SST	-	Sea Surface Temperature
SSTA	-	Sea Surface Temperature Anomaly
STJ	-	Subtropical Jet
TEJ	-	Tropical Easterly Jet
TFRN	-	Terminal Area Forecaster Reference Notebook
TIO	-	Tropical Intraseasonal Oscillation
UAV	-	Unmanned Aerial Vehicle
UN	-	United Nations
US	-	United States
USAF	-	United States Air Force
USJFCOM	-	United States Joint Forces Command
USMC	-	United States Marine Corps
USCENTCOM	-	United States Central Command
USN	-	United States Navy
USSOCCENT	-	United States Special Operations Command
WWW	-	World Wide Web

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ACKNOWLEDGMENTS

Thank you to my advisors, Prof. Tom Murphree and Lt Col Karl Pfeiffer. Your wisdom and guidance were greatly appreciated.

Thank you to my fellow students in the NPS Meteorology Class of 2006.

Special thanks to my wonderful wife and children, Jeffie, Natalie, and Ben for your unconditional love and support.

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I. INTRODUCTION

A. BACKGROUND

Timely, accurate, and relevant assessments of climate and weather, injected into the operational planning cycle at appropriate times, often mean the difference between success or failure for military missions. Unfortunately, military climatology is behind the state of the science. Significant advances in climate science are not typically used by Department of Defense (DoD) centers in creating climate products. Perhaps the most glaring, and readily rectifiable, deficiency is that existing, centrally produced climatology products are based primarily on long term means (LTMs). LTMs are very useful, but they convey an incomplete story at best and can be misleading or inaccurate. For example, LTMs fail to account for known and potentially significant climate variations, (e.g., El Nino/La Nina, Indian Ocean Zonal Mode, Madden Julian Oscillation, etc) that can complicate medium and long range planning considerations and impact operations.

Many of these deficiencies were identified in a recent, independent study chartered by Air Force Weather (AFW) leadership (AFWA 2005). This study specifically recommended that AFW become more integrated in operational and strategic level environmental planning efforts. To do so, the study states that the Air Force Weather Agency (AFWA) and Air Force Combat Climatology Center (AFCCC) will need to improve their "capabilities and methods for providing long-range weather and climate support."

For this study, we developed and applied a process to guide meteorology and oceanography (METOC) personnel in creating new, or updating existing, climatology products using a modern, or smart, climatology approach. A key aspect of this approach is the use of modern data and methods, especially those that allow climate variations from LTM values to be identified and accounted for when developing climatological support for military operations. Operational climatology products generated or updated using our smart climatology process should prove to be both more accurate and more

useful for a broad audience, ranging from researchers to operational users. To explain and demonstrate the use of our process, we have examined climate variations in the Horn of Africa (HOA) and their impacts on military operations in that region.

B. LTM CLIMATE OF THE HOA

The geography, general climatic controls, and LTM climate of the HOA are well described in a comprehensive set of AFCCC publications. Of these, Vojtesak et al. (1990) is the most complete as it compiles most important aspects of the LTM regional climate in one source. The information provided by Vojtesak et al. (1990) is currently being updated (from a long term mean perspective) one country at a time by AFCCC in a series of publications by Giese (e.g., Giese 2004, 2005), but it will be some time before a full update is complete. Additionally, shorter AFCCC narratives capture the LTM climate down to the city, town, and even village level, as well. These publications comprehensively consolidate and present LTM information from a large variety of sources, including climate records and analyses in the scientific literature. As it is not the intent here to duplicate that work, the reader is referred to these publications for complete treatments of the LTM climate of the HOA. However, an abbreviated description derived from these publications is necessary in this study in order to illustrate and lay the groundwork for our subsequent investigation of climate variations in the HOA.

1. Geography of the HOA

Our focus is on the portions of HOA contained within the political boundaries of Eritrea, Ethiopia, Djibouti, Somalia, and Yemen, plus adjacent waters (Figure 1, note: in some studies, this region plus neighboring countries of east Africa is referred to as the Greater HOA.) The ensuing discussion is heavily paraphrased from Vojtesak et al. (1990), which contains a succinct description of the geography and LTM climate of the HOA. Geographically, the western half of the HOA is dominated by the Great Rift mountain system, which runs nearly the entire length of east Africa, extending into the Arabian Peninsula in the extreme north. These mountains average 7,000-8000 feet in height, with some peaks topping 10,000-12,000 feet. The mountains have a marked influence on climate and weather in the HOA, presenting a major natural barrier between modified maritime and continental tropical air masses to the west, and Indian Ocean (IO) maritime tropical air to the east. The only locations below 850 hPa where air masses

from the east and west can converge and interact are the Red Sea - Gulf of Aden corridor and the Turkana Channel in northern Kenya. The eastern half of the HOA can be largely characterized as an alluvial plain, lying at elevations of about 3000 feet or less. The terrain slopes upward from east to west, transitioning from lowlands at the shorelines, then to rolling hills and plateau, until meeting the Great Rift mountain chain.

The complexities of terrain in the HOA make an understanding of local effects key to weather and climate forecasting. Major local factors include elevation, latitude, terrain, and orientation of topographic features to the prevailing large scale flow. With this in mind, Vojtesak et al. (1990) partitioned the HOA into four regions of homogeneous topography, weather, and climate, so called "zones of climatic commonality" (Figure 2). This approach is very useful in simplifying the discussion of the local features and climate from both scientific and operational perspectives.

The Aden Coastal Fringe is the narrow strip of territory that lies along the Gulf of Aden and Red Sea coastlines. It includes coastal portions of Somalia, Djibouti and Yemen. The Indian Ocean (IO) Plains are, essentially, the coastal regions of the HOA, excluding the Aden Coastal Fringe. The Ethiopian Highlands region encompasses most of Ethiopia, as well as small portions of Djibouti, Somalia, and Sudan. The terrain here is mountainous with an average elevation of 5,000 feet. The Yemen Highlands lie along the southeastern edge of the Red Sea on the Arabian Peninsula, the only sub-region far enough north to experience more than infrequent passages of midlatitude weather systems. This sub-region is mountainous, with average elevations of 6,000 feet, and is bounded by the large Saharan and Rub al Khali deserts.

2. General Circulation and the Seasonal Cycle

Large-scale tropospheric circulation features influencing the HOA are largely controlled by (or can be associated with) the Asian monsoon, a seasonal reversal of winds caused by hemispheric-scale, continent-ocean temperature gradients (Ramage et al. 1971, Slingo et al. 2003). Areas of the globe affected by the Asian monsoon are shown in Figure 3. The Asian monsoon affects wind flow at all levels, including lower and upper level jet streams such as the Somali Jet (SJ) and Tropical Easterly Jet (TEJ), and semi-permanent high and low pressure systems. These features are manifested in the local

weather and climate in a variety of ways, depending upon such factors as orientation of terrain to broad-scale flow, and mesoscale effects like land-sea breezes and mountain-valley winds.

During winter (December–March), intense cold over the Asian continent results in subsidence and high surface pressures that peak in January (Figure 4). Low-level winds flow away from the high pressure region, resulting in a dry northeasterly surface flow out of Asia, into the HOA, and across the equator into the southern hemisphere. During summer (June–September), the process and circulation are approximately opposite: intense heating over Asia results in convection and low surface pressures, reaching a peak in July (Figure 5). Cross-equatorial flow out of the Mascarene High from the southern hemisphere is deflected to the right by Coriolis effects and directed toward Asia. The overall pattern is a winter-summer reversal of the low-level winds from northeasterly to southwesterly.

Spring (April-May) and autumn (October-November) are transition seasons between the onset and cessation of the summer and winter monsoons. In the HOA, the seasons are referred to by a variety of names (e.g., Der, Gu, Masika, etc.) depending upon local vernacular. These terms describe the "long rains" that occur in the spring and the "short rains" in the autumn. Much more precipitation falls during the long rains, while the short rains are more variable from year to year (Ogallo 1999).

The HOA seasonal rains are triggered locally by the passage of the Inter-tropical Convergence Zone (ITCZ), a transient area of disturbed weather that marks the boundary between southerly flow and northerly flow. The ITCZ migrates north to south (south to north) during the boreal winter (summer), lagging the overhead position of the sun by about 5° of latitude. However, the progression of the ITCZ can vary greatly locally due to complex terrain or other factors, such as the influence of climate variations on the Asian monsoon (Ogallo 1999). The rainfall response to the ITZC is highly variable. In extremely arid regions, such as Djibouti, for example, the passage of the ITCZ is ordinarily distinguished by little more than a shift in the predominant low-level flow, while more equatorial regions can experience significant shifts in rainfall. Seasonal extreme locations of the ITCZ are shown in Figures 4 and 5.

C. CLIMATE VARIATIONS AND THE HORN OF AFRICA

As described above, LTMs are very useful in military planning. However, they are not comprehensive because they fail to take into account significant climate variations such as El Nino/La Nina (ENLN) that can complicate planning considerations and impact operations. A climate variation is a persistent deviation from the LTM value of a climate system variable (e.g., temperature, winds, pressure, precipitation, etc.) (Murphree 2005a). A persistent deviation is generally considered to be one that lasts for a week or longer. This makes them important in extended range forecasting (e.g., medium range, long range, and seasonal forecasts), which is especially valuable to military planners.

Climate variations can be categorized according to their period (the time the variation lasts). Three primary climate variation categories are especially relevant to DoD operations. The first is intraseasonal variations, which lasts from a week to approximately two months. A major example of an intraseasonal oscillation is the Madden-Julian Oscillation (MJO). The second major category is interannual variations, lasting from one to five years. Examples include ENLN, Indian Ocean Zonal Mode (IOZM), and North Atlantic Oscillation (NAO). The third category is decadal variations. A decadal climate variation lasts from five to 30 years, and examples include the Pacific Decadal Oscillation (PDO). The focus of our work will be on intraseasonal and interannual climate variations, with special consideration given to ENLN and the IOZM, the interactions of the two, and their joint and individual influences on precipitation variability in the HOA.

1. ENLN

During an EN or LN event, a complex and interconnected chain of climate variations occur across the tropical Pacific as the atmosphere-ocean system redistributes thermal energy. EN and LN events have a period of about two to seven years. They tend to begin in May-June and last approximately a year, reaching their maximum intensity in the tropics during November-February (Murphree 2005b.). These events have ramifications for the global circulation ranking only behind the change of seasons in importance and magnitude (Philander 1990). Anomalous patterns and processes in the tropical Pacific associated with ENLN are briefly described and illustrated here, but for a

more detailed treatment the reader is referred to Philander (1990), Murphree (2005b.) or the online module produced by the Cooperative Program for Operational Meteorology, Education and Training (COMET 2003)

EN and LN events and their impacts can be thought of as a sequence of anomalous events (Murphree 2005b.). For EN events, a basic chain of events is as follows:

1. Pacific subtropical highs become anomalously low and/or lows in the southeast Asian - western tropical Pacific become anomalously high.
2. The Pacific trades, which are the surface part of the Hadley-Walker Circulation (HWC), become correspondingly weak (strong).
3. Sea surface temperature (SST) becomes anomalously cool (warm) in the western (eastern) tropical Pacific.
4. Tropical convection become anomalously weak (strong) in the western (eastern) tropical Pacific.
5. Energy, moisture, and momentum transports into and out of the tropical Pacific becomes anomalous in many ways.

The anomalous processes associated with LN are approximately opposite to those of EN, and have been described as "extreme versions of the normal" (Philander 1990). The differences in atmospheric and oceanic processes between normal, EN, and LN periods are clearly seen in the global HWC (Figures 6a, 6b, and 6c), SST anomalies (Figures 7a and 7b), and atmospheric and oceanic structure in the tropical Pacific (Figure 8).

a. Linking ENLN to the HOA

Researchers have explored links between ENLN and precipitation in the HOA using a wide variety of data and methods. Their findings are diverse due to the extremely complex local effects and rainfall patterns in the HOA, but general consensus has been reached on several major points. First, ENLN can be statistically linked, at least weakly, to precipitation variability in the HOA. Second, the season with the most robust precipitation response to ENLN seems to be the boreal autumn. ENLN links to other seasons are weak or inconsistent, and all but ruled out in the literature. This may be because anomalies associated with ENLN events peak in the Pacific during the boreal autumn-winter (Philander 1990). HOA anomalies associated with EN and LN appear to be approximately opposite, with, for example, anomalously high (low) rainfall observed

during EN (LN) years. Finally, the HOA response to LN seems to be more inconsistent and nonlinear. Consequently, we will focus here on the links between ENLN processes and HOA precipitation during the boreal autumn.

Two studies by Ropelewski and Halpert (1987, 1989) employed harmonic analysis and other statistical techniques to examine relationships between surface observations (precipitation and temperature) and the Southern Oscillation Index (SOI) at a global scale. The SOI is a measure of the seasonal fluctuations in the sea level pressure difference between Tahiti and Darwin. Negative (positive) values of the SOI correspond to EN (LN) periods. They identified consistent seasonal, regional precipitation and temperature anomalies for 19 (15) regions of the globe during EN (LN) events. This study documented a tendency for increased (decreased) northern hemisphere winter precipitation (temperatures) over parts of equatorial east Africa during EN events. Using the same techniques in a later study, Ropelewski and Halpert (1989) found roughly opposite responses in the same regions of the globe during LN events, though the statistical relationships were not as strong. A later study by Ropelewski and Halpert (1995) noted, however, that the earlier analyses may have been too simple to quantify the complexities of rainfall for equatorial east Africa.

Farmer et al. (1988) used linear regression to study correlations between a long time series (1901-1984) of precipitation from four coastal Kenyan meteorological stations and the SOI. They found increased (decreased) rainfall during the autumn short rains for EN (LN) years, and a direct correlation between precipitation and the SOI. They also conjectured that improved forecasting skill seemed plausible using June-August SOI to predict September-December rainfall.

A series of studies led by Ogallo (Ogallo 1988; Ogallo et al. 1988; Ogallo 1989) employed more sophisticated statistical methods (e.g., principle components analysis, factor analysis, etc.) and greatly expanded precipitation datasets (approximately 90 reporting stations in east Africa plus the Coupled Ocean-Atmosphere Data Set (COADS)) to examine links between ENLN and sub-regional precipitation variability across portions of east Africa (Kenya, Uganda, Tanzania). Precipitation records in each

study were areally averaged and segregated into multiple homogeneous sub-regions with respect to rainfall in order to minimize undesirable variability due to local effects.

Ogallo (1988) used SOI as a predictor for precipitation variability in each sub-region, while Ogallo et al. (1988) used global SST anomalies (SSTA). Each study reinforced and expanded the Farmer et al. (1988) findings that positive (negative) precipitation anomalies in equatorial east Africa during boreal autumns are associated with EN (LN), with the strongest associations in coastal regions. In Ogallo (1988) it was noted for the first time, in passing, that positive SST anomalies in the IO and Arabian Sea were positively correlated with enhanced boreal autumn precipitation. These anomalies were apparently associated with a weakened northeast (NE) monsoon and attendant strengthening of cross-equatorial southeasterly (SE) flow during the boreal autumn, though mechanisms for these associations were not proposed. Ogallo (1988) also found the LN precipitation response to be somewhat weaker and more inconsistent from event to event.

Beltrando (1990), and Hutchison (1992) employed roughly similar methods to those used by Farmer et al. (1988) to investigate the possibility of using the SOI as a predictive tool for rainfall in Somalia during April-July and September-December. Correlations between prior season SOI values and summer precipitation proved insignificant, and links between the SOI and northwest Somalia were non-existent. This is consistent with the findings of the earlier studies discussed. However, correlations were found between June-August SOI values and September-December rainfall for southern and central Somalia. Each study found rainfall amounts to be high (low) for low (high) SOI values, corresponding to Pacific EN (LN) events.

b. Linking ENLN to the HOA through the IO

Beltrando and Camberlin (1993) computed linear correlations between IO surface pressure, IO SSTs, and areally averaged Somali precipitation records to assess the influence of IO conditions on the HOA. They found that the autumn rains were negatively (positively) correlated with surface pressure, and positively (negatively) correlated with SST, in the western (eastern) IO. Through correlations of Somali precipitation with the SOI, they substantiated earlier findings that autumn rainfall is generally above (below) average during EN (LN) events.

Hastenrath et al. (1993) explored the IO SST-HOA precipitation link during LTM and ENLN conditions. From a comprehensive set of observational datasets assembled from multiple sources, Hastenrath et al. (1993) constructed indices for key atmospheric and oceanic variables (e.g., SST, vector winds, cloudiness, currents, etc.), statistically evaluated them, then outlined a hypothesized mechanism and sequence of events for rainfall variability during the Apr-May and Oct-Nov transition seasons in east Africa, including the HOA.

They found that during an average year, a zonal Walker circulation exists across the equatorial IO with easterlies aloft and westerlies at low-levels with subsidence over the extreme western IO and HOA. The low level westerlies induce eastward upper ocean currents in the equatorial IO that help create relatively cool (warm) SSTs in the western (eastern) IO. Southwesterly winds along the HOA coast induce coastal upwelling and relatively cool SSTs that enhance the zonal pressure gradient that forces the low level westerlies.

In the spring and autumn transition seasons during LN (EN) years, the eastward pressure gradient force that drives the low level westerlies becomes anomalously strong (weak), presumably due to corresponding anomalies in convection over the maritime continent. This tends to intensify (weaken) both the climatological westerlies and eastward ocean currents, resulting in increased (decreased) subsidence over east Africa, as well as decreased (increased) moisture convergence, cloudiness, and precipitation across the region. Interestingly, they found that these effects are especially amplified during a LN year. They attribute this to a strengthened summer monsoon during LN years that tends to reinforce an anomalously cold western IO, which in turn reinforces the mechanism. They also found that these effects are much stronger during the boreal autumn than it is in the boreal spring, similar to past studies.

Hastenrath et al. (1993) provided the first detailed and explicit mechanisms for HOA precipitation variability. Hastenrath et al. (2004) attempted to develop a predictive scheme based on precursor processes in the months leading up to the autumn short rains. The study reaffirmed that these anomalous processes occur during both transition seasons, but that the effect is much stronger during the boreal autumn.

They also found that 70% of the interannual autumn rainfall variability could be accounted for by the concurrent intensity of the equatorial zonal Walker circulation in the IO. However, they could not identify any clear precursors, and had no success in developing a predictive scheme.

A series of studies by Nicholson and co-authors (Nicholson 1997; Nicholson and Kim 1997; Nicholson and Selato 2000) used a modified version of the harmonic analysis techniques employed by Ropelewski and Halpert to examine the links between ENLN, SSTs, and African precipitation variability. In an analysis that included all EN and LN events since 1901, they established strong links between EN and rainfall over many regions of the African continent. For east Africa and the western IO, they found enhanced (suppressed) rainfall during EN (LN) years, especially during the boreal autumn. The EN and LN rainfall anomalies were approximately opposite, but the LN anomalies were weaker.

Perhaps the most significant finding in this series of studies was by Nicholson and Kim (1997). They observed that ENLN influences were confined to those episodes which induced SST anomalies in the IO. Together with the Hastenrath papers, these are the chief early studies to conclude that ENLN influences eastern African precipitation by forcing anomalies in atmospheric circulation that, in turn, impact IO SSTs.

2. The Indian Ocean Zonal Mode (IOZM)

Once researchers established that IO SSTs are a primary factor in forcing precipitation variability in the HOA, particularly in coastal and equatorial regions, the scientific community began conducting more in-depth examinations of processes that cause IO SST variability. This research led to identification of the Indian Ocean Zonal Mode (IOZM). The IOZM is an interannual, coupled atmosphere-ocean mode that creates anomalous SST patterns in the tropical IO. The following several paragraphs describing the IOZM are derived from Saji et al. (1999) and Webster et al. (1999), the first papers to explicitly describe the climate variation and its association with anomalous precipitation in the HOA.

Under normal conditions, IO SSTs are slightly warmer (cooler) in the east (west). Through air-sea interactions, this SST gradient induces a west to east pressure gradient force and an equatorial zonal Walker circulation with westerlies (easterlies) in the lower (upper) troposphere. During a positive IOZM event, SSTs become anomalously warm (cold) temperatures in the western (eastern) IO, and vice versa for a negative IOZM event. Schematic representations of positive and negative IOZM events are shown in Figure 9.

The mechanisms and evolution of the IOZM have been identified by analyzing composites of multiple (Saji et al. 1999) and individual strong events (Webster 1999). Saji et al. (1999) examined composites of the extreme positive IOZM events of 1961, 1967, 1972, 1982, 1994, and 1997, and described the phenomena as follows. Initially, cool SST anomalies appear in the equatorial eastern IO in May or June, accompanied by concurrent, moderate southeasterly wind anomalies in the southeastern tropical IO. Through the summer months, cold anomalies in the eastern IO intensify, and extend westward along the equator. The western tropical IO warms, especially off the coast of east Africa from northern Mozambique to northern Somalia, thereby setting up an anomalous SST dipole across the IO. This dipole gives rise to the term Indian Ocean Dipole (IOD) that is also used to refer to the conditions described by the term IOZM.

As this anomalous SST dipole develops, the equatorial surface westerlies across the IO weaken. In conjunction with the SST and wind anomalies, anomalous strong convection and precipitation results over much of the northern half of eastern Africa and the western IO. At the same time, negative precipitation anomalies develop over the maritime continent.

IOZM events are characterized by SSTA dipoles that are referred to as positive or negative, leading to the terms positive IOZM (or IOD) event and negative IOZM (or IOD) event. Positive or negative IOZM events are often preceded in the year prior by an event of opposite sign. The intensity of the dipole is measured by the dipole mode index (DMI), which is defined by Saji et al. (1999) as "the difference in SST anomaly between the western tropical (50˚E to 80˚E, 10˚S to 10˚N) and eastern tropical (90˚E to 110˚E, 10˚S to equator) Indian Ocean."

The evolution of the IOZM appears to be phase locked to the seasonal cycle, intensifying during late spring through autumn, with a dramatic peak of anomalous features in October, followed by a rapid demise with the approach of the boreal winter. IOZM events usually end in November, but termination can be variable from year to year. Some events terminate as early as August, while an extreme event (e.g., 1961) can last well into January. Both Webster et al. (1999) and Saji et al. (1999) speculate that the onset and termination of IOZM events are forced by and strongly dependent upon the cycle of the Asian summer monsoon. If so, then deviations in the intensity, timing, or location of monsoon circulation components would impact the IOZM.

3. Interactions of ENLN, IOZM, and HOA Precipitation

Most IO climate researchers now agree that IO SSTs are a major factor in forcing precipitation variability in the HOA, particularly in coastal regions during the autumn short rains, and that IO SST variability can be forced by internal or external mechanisms. Considerable debate still exists, however, on the relative roles of and interactions between ENLN, the IOZM, and IO SST anomalies. The IOZM may be an independent entity with self-maintained dynamics internal to the IO (e.g., Saji et al. 1999, Webster et al. 1999, Yamagata et al. 2002). It could be completely dependent upon forcing from, or a simple extension of, Pacific SST anomalies through the Indonesian throughflow region during strong ENLN events (Chambers et al. 1999). Recent research indicates that the likely answer may lie somewhere in the middle of these two opposing views (Black et al. 2003).

Saji et al. (1999) contended that the IOZM is relatively independent of ENLN, driven by dynamics internal to the IO, and they present several findings to support this contention. In a time series of DMI plotted against the NINO3 SST index and IO SSTs, they showed that IOZM and ENLN events have distinct patterns of evolution, with onset, termination, and peaks at different times. SST patterns differed as well between IOZM and EN events. During EN, a general, basin-wide warming across the IO was found, while IOZM events were characterized by a striking SSTA dipole . They also pointed out that the very strong 1987 EN event was not an IOZM year, and a strong IOZM event

during 1994 was not accompanied by an EN event. They argued that co-occurrences of strong ENLN and IOZM are coincidental, and that ENLN does not necessarily predispose the IO to, or initiate, IOZM events.

While Webster et al. (1999) agreed with Saji et al. (1999) that the IOZM involves relatively independent mechanisms, they explored the possibility that the ENLN may initiate or positively reinforce IOZM events. They examined the extreme 1997 positive IOZM event, and suggested that it was unusually strong and persistent because of interactions with a simultaneous strong EN event. Their rationale was that the anomalously warm SSTs over the western IO moistened air that penetrated the African continent resulting in increased convection. The convection amplified the low-level easterly flow and further warmed the western IO via Ekman downwelling. This then strengthened the SST gradient and enhanced precipitation. The net result was a positive feedback process, with the EN event and IOZM event functioning in tandem. While they maintained that the IOZM can be independent of ENLN (as evidenced by the many IOZM years without an EN event), the strong EN and IOZM event that year may have worked in concert to produce the unusually long lasting and intense IOZM event.

Several additional studies closely examined the individual and combined effects of the IOZM and ENLN on SSTs and precipitation patterns in the IO and the HOA (Yamagata et al. 2002; Ashock et al. 2003; Black et al. 2003; Behera et al. 2004). Using composites from multiple observational datasets, Yamagata et al. (2002) documented distinctive SST patterns associated with all IOZM events, pure positive IOZM events, all EN events, and pure EN events. They almost completely discounted the influence of EN, contending that EN events were only associated with significantly warmed SSTs when concurrent with positive IOZM events (Figure 10).

Ashock et al. (2003) statistically examined and compared values of the NINO3 SST index and the DMI to determine the relative contributions of ENLN and IOZM to the zonal equatorial wind anomalies in the IO that force precipitation anomalies in east Africa and the western IO. They found the DMI to be well correlated with the wind anomalies, while NINO3 is not, suggesting independence of the IOZM from ENLN processes. Walker circulation anomalies during pure IOZM events were found to be

distinctly different from those during pure EN events. The convective branch of the Walker circulation, usually located over central Africa, exhibited a clear shift toward east Africa during pure IOZM events, while changes in this convection were diffuse and inconsistent during EN events.

Behera et al. (2004) evaluated 41 years of observational data and a 200-year run of a coupled, atmosphere-ocean general circulation model to determine underlying causes for east African short rains variability. They found that most precipitation variability is associated with the IOZM; that the IOZM's influence is "overwhelming" when compared to that of ENSO; and that the correlation between ENSO and the east African short rains is insignificant when the influence of the IOZM is excluded. Figure 11 taken from their paper shows the differences in rainfall anomaly patterns between pure EN and pure IOZM events. Their model simulation supported the findings of earlier studies we discussed with respect to the basic structure and evolution of the characteristic IOZM features (e.g., anomalies in winds, SSTs, etc.) prior to, during, and after anomalous short rains events. Changes to the mean location of the ascending branch of the Walker circulation, forced by SST anomalies initiated during IOZM events led to anomalous moisture transport into, and enhanced convection over, east Africa.

Black et al. (2003) concluded that strong ENLN forcing can predispose the atmosphere-ocean system in the IO region to an IOZM event and is, therefore, a contributing factor in extreme eastern African rainfall. They contended that the IOZM and ENLN should not be viewed in isolation from one another. Their rationale is that the observed net impact of ENLN on east African rainfall is a result of complex alignment and interplay among several climate factors. They highlight the inconsistencies in the ENLN response by pointing out that African rains were enhanced during three very strong EN events (1972, 1982, and 1997), but they also found that rainfall can be below average during weaker El Nino events (1969, 1976, 1986, 1987, and 1991). And, they point out that the IOZM is inconsistent as well; it is only during extreme IOZM events that east African rainfall is systematically affected.

Consistent with Saji et al. (1999), Yamagata et al. (2002), Ashok et al. (2003), and the early work by Hastenrath et al. (1993), Black et al. (2003) concluded that the most important mechanism for extreme rainfall during positive IOZM events seems to be a weakening of the climatological low level westerlies over the north-central IO and a strong anomalous SST dipole in the tropical IO with positive (negative) SSTAs in the western (eastern) IO. This results in reduced moisture transport away from east Africa and enhanced short rains. Black et al. (2003) contended that dynamical explanations are essential when dealing with this highly complex, situation. The mechanisms for precipitation variability in east Africa are apparently highly non-linear, and cannot be explained well by even the most sophisticated statistical methods. This contention is reinforced by the weak correlations they found between the DMI and east African rainfall, and between the SOI and east African rainfall.

D. OTHER CLIMATE VARIATIONS

ENLN, the IOZM, and their interrelationships and respective influences on IO SSTs have been shown to have strong links to HOA precipitation variability. However, additional major climate variations also have the potential to influence the HOA. In this section, we briefly review two of these variations, the Madden-Julian Oscillation (MJO) and the North Atlantic Oscillation (NAO).

1. The Madden-Julian Oscillation (MJO)

The following discussion on the MJO is derived from multiple sources (Madden and Julian 1994, Murphree 2005c, and Zhang 2005), and readers are encouraged to consult these references for more details. The MJO is an intraseasonal, equatorial, eastward propagating pattern of enhanced and suppressed tropical rainfall. MJOs start over the western IO and propagate the circumference of the globe. They are most prominent over warmer waters, such as those of the IO and western tropical Pacific Ocean. MJOs become less evident, and even nondescript, over the cooler eastern Pacific Ocean. Because the MJO lasts one to two months and occurs in the tropics, it is also known as a 30-60 day oscillation, or tropical intraseasonal oscillation (TIO). MJOs have effects on climate and weather far beyond the equatorial Pacific, including enhanced and suppressed rainfall in subtropical and midlatitude regions (e.g., Stepanek 2006, Vorhees 2006). MJOs also impact tropical cyclone activity. Figure 12 is a schematic

representation of the MJO vertical structure, propagation, and development of the MJO. Figure 13 shows the large scale upper tropospheric circulation anomalies associated with the convective and subsidence regions of the MJO.

Although the MJO starts in the IO, and researchers have known about this climate variation for decades, surprisingly few studies focus on the role of the MJO on precipitation variability in the HOA. Rao et al. (2004) showed that occurrences of MJOs over the equatorial IO were strongly associated with the abrupt termination of major pure IOZM events. This differs from IOZM events that occur with ENLN events, which are shown to terminate primarily due to the seasonal change of the monsoonal winds. Rao et al. (2004) showed that strengthened low level westerlies appeared along the equator during an MJO that forced a downwelling oceanic equatorial Kelvin wave that deepened the thermocline and reduced cold water entrainment in the east.

Matthews (2005) researched African monsoon variability driven by the MJO, and found that the MJO could potentially have ramifications for precipitation in the extreme western regions of the HOA. Finally, Mutai and Ward (1998) explored the influence of intraseasonal oscillations on low level wind patterns and precipitation variability in the HOA. They identified subtle shifts in the low level wind patterns up to five days prior to significant rainfall events in east Africa that have promise for improving extended range forecasting skill. Vorhees (2006) found a link between the MJO and precipitation variability in Southwest Asia, including the Arabian Peninsula and northwestern IO that suggest the MJO may impact precipitation in the HOA.

2. The North Atlantic Oscillation (NAO)

The North Atlantic Oscillation (NAO) is a hemispheric-scale pattern of climate variability that impacts the weather and climate of the North Atlantic and surrounding continents (Hurrell et al. 2003). The NAO occurs in all seasons, but is particularly influential during the northern hemisphere winter (December-March). It is characterized by a shift in atmospheric mass between the North Atlantic subtropical and polar regions. Its intensity and lifecycle are commonly described by an index derived from the sea level pressure difference between Iceland and the Azores.

Visbeck (2006) maintains an NAO information site that provides a summary of anomalous weather patterns associated with the NAO. When the NAO index is positive, pressure is anomalously high (low) in the Azores High (Icelandic Low).. This anomalous pressure difference results in increased storm frequency and more intense winter storms in the subpolar North Atlantic, and a more northerly than normal extratropical storm track across the North Atlantic. The more northerly storm track means wet (dry) winters for northern (southern) Europe. When the NAO index is negative, the subtropical high and Icelandic low are anomalously weak, the extratropical storm track lies further south than average, and northern (southern) Europe is drier (wetter) than normal. The NAO has the potential to influence weather and climate in northern Africa and southwest Asia, including the HOA (Vorhees 2006).

These influences occur in part through alterations of midlatitude synoptic systems that infrequently penetrate into and influence the northern fringes of the HOA. However, we could find no literature to date that directly discusses the influences of the NAO on climate in the HOA. However, Vorhees (2006) found a link between the NAO and precipitation variability in Southwest Asia, including the Arabian Peninsula and northwestern IO that suggest the NAO may impact precipitation in the HOA.

E. SUMMARY OF WHERE WE STAND SCIENTIFICALLY

Many studies exist on the influence of climate variations on the HOA, although they are not nearly as extensive as the body of similar studies for other regions of the world. The climate variations with the most clearly documented links to HOA precipitation are ENLN and the IOZM. These variations seem to have their strongest impacts on HOA precipitation during the boreal autumn. However, considerable debate exists on the relative influences of each on the processes that shape precipitation variability across the IO basin and HOA, and on the interactions between the two climate variations. We researched two additional climate variations in the literature, the NAO and MJO. The MJO appears to influence HOA precipitation variability in intriguing ways that are just beginning to be identified. Our literature review revealed that the NAO has not been clearly linked, to date, to climate variability in the HOA.

Our literature review also revealed an interesting evolution over the last two decades in the scientific understanding of the impacts of ENLN and the IOZM on the HOA. As recently as ten years ago, increased understanding of ENLN seemed to be the key for improving climate scale forecasts of HOA rainfall. However, studies of ENLN processes revealed that IO SST variability is a major factor in HOA precipitation variations. ENLN may play a relatively indirect role through modulation of atmospheric and oceanic processes that shape IO SSTs. Subsequent investigations of IO SST variability prompted by the prior ENLN research uncovered the existence of the IOZM, which likely plays a greater role in IO SST variability and precipitation anomalies than ENLN. The current consensus seems to be that each climate variation plays a role in precipitation variability in the HOA, but the picture remains conflicted and muddled regarding the relative influences of, and interactions between, the two.

Additional gaps and disagreements remain in the literature as well. First, either due to the dearth of data or researcher affiliations and biases, most studies focus on the equatorial regions of east Africa, rather than the HOA itself. Climate variations in the HOA have been much less extensively studied than climate variations in Kenya and further to the south in east Africa. Additionally, very little has been done to identify the links between climate variations, such as ENLN and the IOZM, and the HOA in ways that facilitate extended range forecasting for the HOA.

F. MILITARY CLIMATOLOGY ISSUES

1. Past U.S. Military Operations in the HOA

The United States (U.S.) has been involved militarily in the HOA on a number of past occasions. The most significant operation to date was Operation RESTORE HOPE, a United Nations (U.N.) sponsored intervention in Somalia (Allard 1995). RESTORE HOPE was initiated to avert humanitarian catastrophe precipitated by severe famine, lawlessness, and warlordism that transpired following the collapse of Somalia's Marxist government. At the height of U.S. involvement from Dec 1992-May 1993, 38,000 troops from 21 coalition nations were participating, of which 28,000 were contributed by the U.S (Allard 1995). Missions were multi-faceted and included: air, sea, and land-based logistics; security forces; amphibious forces; aerial reconnaissance; engineering and

heavy construction units; and a fully operational Civil-Military Operations Center (CMOC) to coordinate U.S. contributions to humanitarian relief operations from government and non-government entities.

Precipitated at least in part by the Black Hawk Down incident, the U.S. promptly disengaged from the HOA once RESTORE HOPE transitioned to full U.N. leadership in 1993 (Allard 1995). The region subsequently devolved into a fertile breeding ground for terrorist groups such as Al Qaeda. Terrorist attacks on U.S. interests in and around the HOA ensued, and included the 1998 U.S. embassy bombings in Kenya and Tanzania, as well as an Al Qaeda attack on the USS Cole in Yemen during 2000. This string of terrorist strikes that culminated in the September 2001 terrorist attacks on U.S. soil brought the U.S. government to the realization that strategic engagement in the HOA and other at-risk regions is vital to winning the Global War on Terrorism (GWOT). Endemic poverty and underdevelopment, political turmoil, weak governments, and close proximity to Islamic fundamentalist centers in the Arab world continue to make the HOA especially susceptible to international terrorist activity (Iyob and Keller 2005, Mills 2004).

As part of the reassessment of U.S. engagement priorities, the Combined Joint Task Force-Horn of Africa (CJTF-HOA) organization was established in Djibouti in 2002 to coordinate military operations in the HOA. This U.S. Central Command (USCENTCOM) organization oversees at least eighteen hundred troops ashore, plus a large contingent of afloat personnel in the nearby Gulf of Aden (Iyob and Keller 2005). Supplementary bare-basing agreements with key governments in the region give U.S. forces the ability to deploy quickly in “lily-pad” fashion to regional trouble spots (Mills 2004). Given the HOA’s strategic importance, it is reasonable to assume that the U.S. will maintain a presence in the region for the foreseeable future. Recognizing the importance of the region, there have been discussions since September 11, 2001 of altering the Unified Command Plan to elevate the CJTF-HOA to regional sub-unified command status (Catoire 2001).

2. Present and Likely Future Military Operations in the HOA

Although it is possible, it appears unlikely that the U.S. would be involved in operations in the HOA on the magnitude and complexity of RESTORE HOPE any time soon. Under the umbrella of CJTF-HOA, however, the U.S. remains engaged daily in

many of the types of stability activities that took place then, albeit with a smaller presence. The CJTF-HOA public relations site contains links to multiple news articles that highlight the efforts U.S. military personnel are making to assist the populace, including installing water pumps, digging wells, rebuilding schools and medical facilities, and coordinating civil-military efforts and non-governmental organization (NGO) activities (CJTF-HOA 2006). They are training national military forces in mine clearing, border security, basic anti-terrorism missions, and coastal patrol. The U.S. Navy is engaged in maritime intercept operations (MIO) of smugglers and pirates. One of the most important ongoing missions in support of counter-terrorism is overhead intelligence, surveillance, and reconnaissance (ISR) data collection conducted from a variety of platforms.

Small-footprint, less intrusive operations are likely to continue as the norm in the CJTF-HOA area of responsibility (AOR). In a recent news article (Brandon 2006), Maj. Gen. Timothy Ghormley, CJTF-HOA commander, is quoted, "We are in a generational fight for hearts and minds…We do water projects and build schools that help a poor child in a village, and in 20 years that child will remember us." With successful engagement, strike operations or massive deployments will be less likely in the near future.

3. Climatological Factors Affecting Probable Military Operations in the HOA

Given the LTM conditions, potential impacts of climate variations, and likely military missions, there are several key climatological variables that METOC officers and operational commanders must evaluate when planning operations. For all missions, precipitation variability is of paramount importance. The populace is highly reliant upon subsistence agriculture which is, by definition, tenuous in nature. Famine precipitated by flood or drought can destabilize the situation on the ground, which could pressure the U.S. into increased military, economic, or political involvement in the region. Floods have an additional negative impact in that they can hamper operations involving ground components, including movement, logistics, and construction activities.

For ISR in particular, cloud cover influences sensor load-outs on collections platforms. Preferred sensors are unable to penetrate thick cloud cover. Finally, surface wind direction and intensity are important to all the operations mentioned above, but

especially for conducting naval operations off the coast of the HOA. If winds are abnormally strong, high sea states interfere with small boat operations and MIOs of smugglers or pirates, a major issue. Closely related to precipitation, clouds, and winds, thunderstorm activity also inhibits the full-spectrum of operations. In particular, thunderstorms can cancel launch and recovery of aircraft used for movement of personnel and supplies, ISR, and strike operations.

4. The METOC Officer in the Operational Planning Process

Considerable formal doctrine and informal guidance details the roles and staff responsibilities of the METOC officer. Optimal points in the decision process where climatological information should be injected are also clearly defined. The following two sections discuss the existing doctrine and guidance. Given the scope and goals of this thesis, we have chosen to focus on joint doctrine and guidance. The joint framework provides a template on which service-level METOC support can be based. Additionally, the joint documents discussed here contain comprehensive reference lists of service-specific METOC guidance. Therefore, although our discussion revolves around joint guidance, the information discussed here is very applicable to service-specific operations.

a. Providing Operational Climatological Support

Joint Pub 3-59 (JP 3-59), Joint Doctrine, Tactics, Techniques, and Procedures for Meteorological Operations (Joint Staff 1999) is the authoritative document on METOC operations from the joint perspective. It is primarily written for joint force commands and subordinate staffs, but the information it contains applies down to the tactical level. The publication sets forth the joint doctrine and tactics, techniques, and procedures for the planning and execution of METOC operations throughout the range of military operations. JP 3-59 furnishes an overview of the importance of METOC conditions to joint force operations; discusses the structure of combatant command METOC organizations in peace and in war; covers overarching principles of METOC support; and discusses METOC operations in the joint force environment. Perhaps most importantly, JP 3-59 identifies specific planning documents (e.g., annexes) for which climatological information is needed.

With respect to climatological products, much is not covered in JP 3-59. The publication answers questions about where, what, when, and why climatological support is needed, but not the how to provide this support This is not necessarily a flaw, since JP 3-59 is not designed to cover technical aspects of meteorological and climatological support. The document directs the joint force METOC officer to organizations such as AFCCC and Fleet Numerical Meteorological and Oceanographic Detachment (FLENUMMETOCDET), Asheville for climatology products. It also provides a comprehensive listing of the standard types of products that can be obtained from these centralized climatology centers.

The Joint METOC Handbook (JMH), 4th Edition (USJFCOM 2002), replicates much of JP 3-59, but goes into more depth in several subject areas applicable to METOC staff officers. In effect, the JMH serves as a bridge between highly technical meteorological documents and joint doctrine by supplementing JP 3-59 with more technical information. The most notable feature is Appendix F, which provides several examples of tailoring meteorological and climatological data into impacts matrices.

The Weather Staff Officer's Guide to Climatology (Higdon 2003) is an AFCCC-produced guide to incorporating climatology into the staff planning process. In contrast to the joint publications, it broaches the topic of climatology from a technician's perspective, covering standard definitions of climatology and its limitations. The guide contains suggestions and guidelines for determining customer needs, and discusses formatting and optimal sequences for presenting standard climatological information to operational users. Also included is a descriptive list of AFCCC's available climatology products and guidance on appropriate usage. A final section discusses organization of climatological resources in an operational unit.

Higdon (2003) provides rules suggested for deciphering customer needs in terms of military impacts. These rules are brief, but underscore some very important lessons learned from experienced operational meteorologists. However, this document promotes the commonly held paradigm in the DoD that climatology is based solely on long-term means. The authors state that the staff weather officer should "never try to use climatological information as a long-range forecast for a specific event." While this is

generally correct, properly applied, state-of-the-art climate data, analyses, and forecasts can make medium and long-range military climate forecasts much more precise than they are at the present. In this study, we make the case for doing so, and fill some existing gaps in military climatology.

Finally, broad criteria for determining the operational impacts of METOC phenomena are found in each of the joint publications discussed. However, these criteria are not authoritative in nature, serving as baseline guidance only. The services may define impacts to suit their operational needs. Additionally, combatant commanders have wide latitude to fine-tune impacts criteria through rules of engagement (ROE). Commanders can stipulate more, or less, restrictive operational criteria to facilitate mission accomplishment. These types of adjustments are the reason the METOC officer must be well-integrated throughout the operational planning process.

5. Modern, or Smart, Climatology

Murphree (2005d) and Ford and Murphree (2006) define and describe both traditional and modern, or smart, climatology, compare and contrast the two approaches, and make a case for using modern climatology in military applications. The following discussion is largely paraphrased from those sources. Traditional climatology products focus on LTMs, especially the description of LTM seasonal cycles. Smart climatology is a major advance forward from traditional climatology approaches because it incorporates modern developments in climate science to include analysis of anomalous trends and oscillations, reanalysis, downscaling, and climate forecasting.

Smart climate analysis of anomalous trends and oscillations combines LTM climate patterns and the dynamical processes that drive those patterns with an understanding of climate variations (e.g., ENLN, IOZM, MJO, NAO, etc.) that can cause significant deviations from the LTMs. Much of this work involves the use of reanalysis methods. Reanalysis is the analysis of climate system components using modern analysis processes to analyze past states of the climate system. Reanalysis is the same as standard atmospheric or oceanic analysis, except that it is not done in real time, and it involves consistent analysis procedures applied to all times in the reanalysis period (e.g., the background field is made by a numerical weather prediction (NWP) model that does not change over the entire period of the reanalysis). In real time operational analysis,

frequent changes are made to the analysis procedures (e.g., changes to model features, such as physics and assimilation schemes). While these changes optimize operational forecasting, they introduce artificial temporal jumps and discontinuities that are detrimental to climate scale analyses.

Fixing model characteristics for the analysis of multi-year or multi-decadal periods yields complete, gridded data that are as temporally homogeneous as possible, which in turn facilitates climate analyses. Reanalysis data also includes many derived fields (surface heating, soil moisture, etc.) for which direct observations are sparse. Many operational organizations generate reanalyses of the atmosphere and ocean for use in climate studies, including the National Oceanographic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), the European Center for Medium-Range Weather Forecasting (ECMWF), the Naval Research Laboratory (NRL), AFCCC, and many universities.

Downscaling is the process of converting fields with relatively low spatial resolution, such as those from a global reanalysis, to higher resolution fields. The process typically involves using a mesoscale model to generate mesoscale analyses or reanalyses from low resolution inputs to the model. Downscaling can yield a much clearer understanding of fine scale processes that contribute to climate variability in a region.

Climate forecasts are predictions of the future state of the climate, much as we think of weather forecasts but at longer time scales (e.g., weeks, months, years, decades). Climate forecasts can be thought of as incorporating all the elements of modern climate science to arrive at accurate characterizations of the future state of the climate. Many of the civilian organizations that generate reanalysis data also generate climate forecasts for many regions of the world (e.g., NOAA).

Applied climatology is scientific analysis of climatic data for specific operational purposes. By this definition, military climatology is a type of applied climatology. Good military climatology products should infuse all of the scientific elements of smart climatology, and tailor the results to the specific tactical, operational, or strategic requirements of the supported command or staff. The goal: mission-tailored, timely,

accurate, relevant climatological decision aids that add value through the full spectrum of military operations, from long range deployment planning to combat operations (e.g., weapons and target selections, force positioning, etc.). Smart military climatology provides a more comprehensive view of the climate system and is much better suited than traditional climatology for supporting combatant commanders.

6. Present State of Operational Planning Products

It has been demonstrated repeatedly that accurate assessments of climate and weather impacts can make the difference between mission success and failure for any given military operation. Unfortunately, one may argue that currently available climatology products and services from DoD organizations, though produced with quality datasets and increasingly sophisticated, fine-scale models and visualizations are, in general, deficient from the perspectives of smart climatology and military utility.

Our survey of numerous military plan annexes as well as DoD-produced climate studies, graphics, and textual products revealed that they are based almost exclusively on LTMs. A comprehensive search of the Air Force Weather Technical Library (AFWTL) holdings garnered no military-produced publications or guides that specifically address the impact of climate variations on military operations in the HOA, or any other theater of interest. AFCCC has been very innovative in the realm of packaging meteorological data into new and improved formats that are easily usable by meteorological personnel (e.g., spatial visualizations, meteograms, wind roses, etc.). The fact remains, however, that these products are based mainly on LTMs, with little or no consideration of climate variations.

With respect to the use of reanalyses and downscaled data, AFCCC has generated a mesoscale reanalysis using its Advanced Climate Modeling and Environmental Simulations (ACMES) system. AFCCC has made visualizations and other products derived from the ACMES data available to operational users through its website. Products generated from this data have also been widely incorporated into recently updated climatology publications such as those by Giese (2004, 2005). However, a recent informal study by Feckter and Applequist (2005) indicated that the ACMES data is flawed for key variables and times in militarily critical parts of east Asia, and is most likely inaccurate for other areas of the globe as well.

To our knowledge, the only climate forecast products that are routinely created by the U.S. military are the seasonal heating outlooks created by the Naval long-range forecasting unit in Norfolk, Virginia. These forecasts are based on seasonal temperature forecasts from the NOAA Climate Prediction Center (CPC). The primary Naval products are estimates of the demand for heating fuels for CONUS bases based on the CPC temperature forecasts. Unfortunately, this Naval unit is presently scheduled to be shut down due to budget reallocations (Rivenbark 2006).

Climate forecasts for select areas are created by civilian and other government organizations, but few line military forecasters are aware that this information is available to be leveraged for operational planning. Even if it were common knowledge in military climatology circles that these products are available, no formal training in their use exists in DoD channels. Additionally, civilian organizations have differing objectives and priorities than the military, so there is no guarantee that their climate forecasts are suitable for military uses, or available for military regions of interest. An independent study directed by AFW (Air Force Weather) identified the need for the military to explore climate forecasting (AFWA 2005).

From the perspective of military utility, most centrally produced DoD climate products are overly broad and insufficiently tailored to operations, rendering them of little value for most mission planning. Though forward strides have been made in recent years, these products are also, for the most part, overly technical for use by non-meteorologists. The extensive repackaging and tailoring required by end users to elevate the products to suitable standards is time consuming, and the lack of guidance on creating operational products inevitably results in large inconsistencies between supported organizations.

A division of labor must be made at some juncture, and the operational meteorologist is the true expert on the weather thresholds of, and impacts to, supported missions. However, today's operational weather units have been greatly down-sized; in some instances to just half the personnel they had just five years ago. These small units rarely have the appropriate personnel, time, or funds needed to make centrally produced DoD products useful to their customers. Planning staffs at headquarters level are even

smaller, with a much broader scope of operations to consider. The operational expertise lies at the unit level or planning staff, while the centers of mass for resources (personnel and data) and scientific expertise reside at the DoD climate centers or academic institutions. Neither seems to be an ideal fit for the task of tailoring climatology products to climate variations.

A series of briefings produced by the weather cell at the Air Force Operations Group (e.g., AFOG 2001a, 2001b) provide a model for tailoring climatology products to very specific missions and weapons systems for various militarily significant locations around the globe. However, many of the same shortcomings that exist in centrally produced climatology products are inherent in these briefings as well. The briefings are highly operationally focused, but are based almost entirely on LTMs, with little discussion of climate variations. The format has not been institutionalized throughout AFW, and no entity is formally carrying on this work. The briefings are informal, so they have not been peer-reviewed or checked for accuracy. Perhaps most importantly, the briefings have only been created for a few locations, and most were created after operations were already underway. In short, these briefings are designed for operations, but could benefit greatly from smart climatology approaches.

G. SUMMARY OF WHERE WE STAND OPERATIONALLY

From a science perspective, standard, existing operational DoD climatology products are deficient because they are not based on smart climatology methods (e.g., addressing climate variations, state of the art climate analysis and forecasting, tailoring to operations, etc.). The existing products are incomplete in part because they fail to address climate variations relevant to operational planning and impacts assessments. In addition, almost no climate forecasts are produced by DoD organizations, and readily available climate forecasts produced by civilian sources are rarely leveraged to improve the planning process.

From the operational perspective, pockets of excellence exist in the realm of tailoring climatological information to operational impacts (e.g., AFOG briefings), but deficiencies remain because these products are derived wholly from standard climatology data and products. Although the absence of smart climatology in DoD products has been recently recognized, no entity has fully stepped up to addressing this shortcoming. In the

past, DoD centers have resisted the notion of updating current and new climatology products using the smart climatology model due to resource limitations and the perceived or stated scope of their missions. Field units (weather flights and planning staffs) possess the expertise on mission impacts to tailor data, but they have neither the time nor the personnel resources to do this work efficiently.

Finally, there is insufficient guidance to direct the METOC officer in creating smart operational climatology products. The role of the METOC officer in all major steps of the planning process is very well defined in joint and service doctrine, as are impacts criteria for translating climatology to impacts. However, there is an art to injecting climatology data into operational planning that can only be learned on the job. In addition, there are no military documents that clearly describe a process by which METOC officers can merge modern climate science with operational information to create smart or modern climatology products. No objective guidance exists on the best way to incorporate information on climate variations into climate impacts matrices. The collective outcome of the deficiencies above is inconsistent, inadequate, and potentially inaccurate climatological products in support of the warfighter.

H. DESIGN OF THIS STUDY

This study is motivated primarily by major unresolved issues in military climatology:

1. Military climatology is behind the times. Existing, centrally produced DoD climate studies, graphical visualizations, and textual products are based almost exclusively on LTMs. While LTMs are useful, they convey an incomplete story at best, and are inaccurate or misleading at worst, because they fail to account for known and potentially significant climate variations that can significantly impact mission planning and execution. The inherent weaknesses of standard LTM climatology products are compounded by the reality that U.S. forces are most likely to deploy to regions that suffer from low quality data, or even a complete lack of LTM observational data. Existing and future military climatology products would benefit immensely from an infusion of modern climate science and information. For this study, we developed and applied a method for producing smart climatological analyses for a region with little data but with great importance to the U.S. military.

2. Tailoring climate data to operational missions is, in general, a real strength of DoD field units (e.g., AFOG briefings). Most operational units know their customers and supported missions well. However, the quality of

tailored products varies greatly from one unit to another due to a broad spectrum of experience levels and lack of formal, institutionalized training on building climatology planning products. Additionally, operational plan annexes and other products are developed using standard LTM climatology products. For this study, we developed and applied a process by which to assess operational impacts using smart climatology.

3. Finally, processes exist for doing DoD operational climatology. However, this guidance is scattered throughout multiple formal and informal publications, and does not address smart climatology processes. A major need exists in military climatology for a synthesis of smart climatology processes and operational tailoring in one well defined process. For this study, we developed and applied a method for creating such syntheses.

Given these unresolved issues, our primary goal is to design and demonstrate a readily reproducible process for updating existing or creating new operationally tailored climatology products based on smart climatology processes. Operational climatology products that are generated or updated using the process presented in this study should prove to be both more accurate and more useful as decision aids to a broad audience, ranging from researchers to operational users to combatant commanders.

To achieve our primary goal, we have researched climate variations with the potential to affect a region with strategic importance, the Horn of Africa. We focused on the following questions:

1. What climate variations impact climate in the HOA?
2. What are the dynamical mechanisms that produce these impacts?
3. How do these impacts translate to military operational impacts assessments?

The existing literature led us to focus on precipitation variability in the HOA during the boreal autumn. Within this context, we identified several gaps and unresolved issues:

1. Most prior scientific studies of climate variations affecting precipitation in the HOA have been statistical in nature, with relatively few studies analyzing the dynamical mechanisms that created these impacts. Studies that have discussed dynamical patterns and processes have not presented their results in a fashion that a military forecaster can readily understand and translate to operational impacts. In this study, we analyzed the IO basin circulation anomalies associated with EN, LN, and the IOZM, and their relative roles in forcing anomalous precipitation in the HOA. We also characterized the related processes and relationships in a manner designed to be useful to military meteorologists.

2. Most prior studies were focused on equatorial regions of east Africa and the IO. This excludes large regions of the HOA that are of interest to combatant commanders. Where possible, we extended impacts assessments to the HOA.

3. No clear consensus exists regarding the relative roles of, and interactions between, ENLN, the IOZM, and SST, and precipitation variability in the IO and the HOA. Though links have been identified, they are complicated, inconsistent, and difficult to characterize. Because so much debate remains, we examine various combinations of these anomalies in hopes of clarifying issues from a military perspective. Though resolution of these issues is beyond the scope of this thesis, the relationships are worthy of exploration in a military context. We have done just that, and we hope that the discussion provided in this study on the various scientific perspectives will add to the debate and assist operational users in understanding the overall impacts of these variations on military missions.

4. It is likely that additional climate variations besides ENLN and IOZM impact the HOA during the autumn, and that climate variations have important impacts on the HOA in seasons other than autumn. We did a preliminary assessment of the impacts of the MJO and the NAO and concluded that the MJO is a promising candidate for further research. The recent research by Vorhees (2006) on ENLN, IOZM, MJO, and NAO impacts on the northern IO and southwest Asia strongly supports this conclusion.

Based on our literature review and initial examination of reanalysis data, our main scientific hypotheses are:

1. EN (LN) events are associated with enhanced (suppressed) precipitation in large areas of the HOA during the Oct-Nov short rains season.

2. Positive (negative) IOZM events cause enhanced (suppressed) precipitation in large areas of the HOA as well during the same season. Most EN events occur concurrently with positive IOZM events, and a large percentage of negative IOZM events are concurrent with LN events. Thus, concurrent EN and positive IOZM (LN and negative IOZM) events will result in especially enhanced (suppressed) rainfall for large areas of the HOA. The basic dynamical patterns and processes behind these rainfall anomalies can be explained in terms of Rossby-Kelvin wave dynamics (Matsuno 1966; Gill 1980). These anomalies and underlying processes can be characterized in a manner that facilitates their use in developing climatological products for use in military planning.

I. ORGANIZATION

In the following chapter, our data and research methods are presented. Chapter III presents our main results. Chapter IV provides our summary of results, discussions and conclusions, and suggestions for future research.

II. DATA AND METHODS

A. NCEP REANALYSIS DATASET

The climate data used in this study is from the National Centers for Environmental Prediction (NCEP) reanalysis data set (Kalnay et al. 1996, Kistler et al. 2001), composited to monthly means. The reanalysis data set was derived from historical observations that have been quality controlled and modeled with a modernized, fixed version of the NCEP global data assimilation system. Background information on the reanalysis data can be found in Kalnay et al. (1996), Kistler et al. (2001), or on the CDC world wide web site (CDC 2006).

Our study is limited to years beyond 1969 because previous studies established that the NCEP reanalysis dataset is problematic for tropical Africa prior to that year. For example, Pocard et al. (2000) found major artificial shifts in time series of most variables prior to 1968 for our area of interest. They hypothesized that these shifts reflect some problem with data assimilation for the region by the NCEP model. The errors render the data prior to this time unreliable for studying long-term climate variations. This contention is supported by Camberlin et al. (2001).

B. MULTIVARIATE ENSO INDEX (MEI)

Many indices have been developed and employed over time to characterize EN or LN onset, cessation, and intensity. Discussions of the historical evolution of various ENLN indices are found in Ford (2000) and Hildebrand (2001). All of these indices are based upon a variety of measurable atmospheric and oceanic elements, including sea level pressure and sea surface temperature at key locations. We used the Multivariate ENSO Index (MEI) to rank and identify strong EN and LN events for individual and composite analyses. The MEI is more broadly based than most ENLN indices because it captures the concurrent variations of multiple key variables (Wolter and Timlin 1993, 1998).

In brief, the MEI integrates six key observed oceanic and atmospheric variables into one compact index to characterize and monitor the past and present states of ENLN in the tropical Pacific. The six variables used are: sea-level pressure; zonal and

meridional components of the surface wind; sea surface temperature; surface air temperature; and total cloudiness fraction of the sky. MEI values are individually computed for twelve sliding bi-monthly seasons. For example, values represent Oct/Nov, Nov/Dec, and so on. The procedure involves spatial filtering of the six individual fields into clusters, then calculating the MEI as the first unrotated principal component of all fields combined. Resulting values are standardized for each bi-monthly period, as well as the 1950-1993 reference period. MEI values are updated monthly at the NOAA Climate Diagnostics Center (CDC) using data from near real time ship and buoy observations. A positive (negative) MEI value represents an EN (LN). A time series of MEI values for October-November since 1969 is provided in Figure 14. For a complete description of the MEI, see Wolter and Timlin (1993, 1988).

C. INDIAN OCEAN DIPOLE MODE INDEX (DMI)

We used the Indian Ocean Dipole Mode Index (DMI) to identify positive and negative IOZM events. The DMI is defined by Saji et al. (1999) as the normalized SST anomaly in the western tropical IO (an area average for 50˚E to 80˚E, 10˚S to 10˚N) minus that in the eastern tropical IO (an area average for 90˚E to 110˚E, 10˚S to equator). Figure 15, adapted from Saji et al. (1999), illustrates these regions. A positive (negative) DMI value corresponds to a positive (negative) IOZM event. A time series of seasonal (May-November) DMI values for October-November since 1969 is shown in Figure 16.

Periodicities longer than seven years are filtered out before calculating the index, and all values are normalized by the standard deviation of the DMI. The DMI series we used contains one value per year to characterize the state of the IOZM, and is an average of values from June through October. As the IOZM is an atmospheric-oceanic climate variation, it can be characterized by indices derived from many different variables (e.g., outgoing longwave radiation, sea level pressure, etc), and can be calculated on time scales other than monthly. Additional indices, and values of the seasonal index we used are found at the DMI homepage (Rao 2005) .

D. EVENT SELECTION AND COMPOSITING APPROACH

Using the MEI and DMI, we identified the five strongest: EN (1982, 1997, 1972, 1987, and 1994); LN (1975, 1973, 1988, 1971, and 1974); positive IOZM (1994, 1972,

1997, 1982, and 1983); and negative IOZM (1996, 1992, 1970, 1971, and 1998) events since 1969 for composite analysis. The ten strongest of these events and their relative rankings are shown in Table 1.

Year	Strong IOZM (-)	Strong IOZM (+)	Strong EN	Strong LN
1969				
1970		3		7
1971		4		4
1972	2		3	
1973		9		2
1974				5
1975		10		1
1976	10			
1977	7		7	
1978				
1979				
1980				
1981				
1982	4		1	
1983	5			
1984		8		
1985				
1986			9	
1987	9		4	
1988				3
1989		6		
1990				
1991	8		6	
1992		2		
1993			10	
1994	1		5	
1995		7		10
1996		1		
1997	3		2	
1998		5		6
1999	6			8
2000				9
2001				
2002			8	

Table 1. Ten strongest positive IOZM (IOZM +), negative IOZM (IOZM -), EN and LN events since 1969. The numbers in each colored box represents the rank (1-10) of the indicated event. IOZM events are ranked using the Indian Ocean Dipole Mode Index (DMI, (Rao, 2006)). EN and LN events are ranked using the Multivariate ENSO Index (MEI, Wolter, 1998)). [table titles go at the top]

We selected the five strongest events for composite analysis because including weaker events, or using more than five events introduced undesirable variability that tended to obscure important climate patterns, processes, and mechanisms of interest. Key climate variables analyzed, abbreviations used (where applicable), and units are listed in Table 2.

Variable	Abbreviation	Units
Sea surface temperature	SST	degrees Celsius (˚C)
Air temperature at 10 m	T air/air temperature	degrees Celsius (˚C)
200 hPa geopotential heights	200 hPa GPH	geopotential meters (GPM)
850 hPa geopotential heights	850 hPa GPH	geopotential meters (GPM)
200 hPa vector winds	-	meters/second (m/s)
850 hPa vector winds	-	meters/second (m/s)
Specific humidity	SH	grams/centimeter^3 (g/cm^3)
500 hPa vertical velocity	Omega	Pascals/second (Pa/s)
Precipitation rate	precip rate	millimeters/day (mm/day)
Outgoing longwave radiation	OLR	watts/ meter^2 (w/m^2)
Volumetric Soil Moisture (0-10cm)	soil moisture	fraction

Table 2. Key climate variables analyzed, with abbreviations and units

We examined LTM (1969-2005) composites first to establish a baseline for key climate variables and to confirm that the NCEP reanalysis fields resemble other descriptions of the LTMs. The composite for any given variable is simply the mean of the members of the composite. For example, the mean 200 hPa GPH of the five Oct-Nov periods used for the EN composite. We then analyzed the EN and LN composite fields, and the EN and LN composite anomalies with respect to the LTM fields. This process

facilitated identification of specific regions impacted by the climate variations, and allowed us to qualitatively and quantitatively establish impacts to translate to operational impacts.

Note that the five strong EN and five strong positive IOZM composites differed only by a single event (1987 for EN and 1983 for positive IOZM). Conversely, there was just one common event between the five strong LN and five negative IOZM composites (1971). Because the EN and positive IOZM composites differed by only one event, and initial comparisons of LN and negative IOZM events revealed stronger and more coherent climate responses in LN than in negative IOZM years, we confined the bulk of our analyses to the EN and LN composites, rather than the IOZM composites.

Our analysis approach differed in many ways from those taken by most of the studies discussed in the literature review. First, most previous studies relied primarily upon observational data, especially station data, whereas we used composites of NCEP reanalysis variables to examine patterns and processes in LTM, EN, and LN fields. The criteria we used for selecting events was also different, as we used the MEI (based upon multiple variables) rather than other ENLN indices based upon single variables, such as equatorial Pacific SST indices or the SOI. We composited relatively small numbers of strong EN and LN events, rather than a mixture of strong and weak events. We limited our study to events that occurred after the advent of the satellite era, since that meant the reanalyses were based on more data. Finally, our focus was on the HOA proper, rather than on the broader regions of east Africa on which most previous studies focused..

Frequently, anomalies are quite strong and clearly illustrate dynamically understandable patterns. In our HOA cases, the anomalies were often weak, and difficult to discern or interpret. Although it is often difficult to interpret and understand patterns and processes associated with weak anomalies, this does not imply that they are unimportant. There are several reasons for this. First, the percent deviation from the LTM represented by the anomalies can be more significant than the magnitude of the anomaly itself. For example, in an arid environment, a relatively small positive or negative precipitation anomaly can have large ramifications for flooding or drought.

One should also keep in mind that the interactions between small anomalies, and the role of small anomalies in instigating subsequent larger anomalies, can be complicated but quite significant, with much larger ramifications than simple magnitudes would imply. Subtle anomalies can often play a role in initiating stronger and more dynamically interpretable anomalies. For example, weak wind anomalies can lead to large moisture and energy flux anomalies from the ocean, which can generate large moisture and energy advection anomalies in the atmosphere.

Repetition of small anomalies (e.g., similar anomalies developing each time there is an EN event) can reveal elusive climatic patterns and processes. Antisymmetry of small anomalies (e.g., opposite anomalies developing during EN and LN situations) can also help reveal these patterns and processes. Thus, even weak, but spatially coherent and temporally persistent anomalies can provide clues to larger patterns and processes as well.

The analysis of anomaly fields can be complicated when the anomaly fields oppose the actual fields. For instance, consider a case when the anomalous winds were onshore and there were positive precipitation anomalies over land, but the actual winds were offshore. One might infer from the actual winds that the precipitation anomalies over land should have been negative. The existence of positive precipitation anomalies over land indicates that more days of onshore flow occurred than normal, and/or the onshore flow was more intense and/or advected more moisture than normal, thus leading to the positive precipitation anomalies.

E. COMPUTING METHODS

We used custom shell scripts to extract data from NCEP reanalysis gridded binary (GRIB) data, and the National Center for Atmospheric Research (NCAR) Command Language (NCL) to visualize and analyze the data. NCL is an interpreted program language designed specifically for scientific data processing and visualization. The language has robust file input and output, with the capability to read in all standard climatological data formats (e.g., the GRIB used in this study). Complete documentation for NCL can be found online (NCAR 2006).

F. SMART CLIMATOLOGY PROCESS

In brief, our methods for determining operational impacts were comprised of both scientific and operational components. The science component included a thorough review of the climate literature to define LTMs and identify climate variations having the potential to impact the area of interest, the HOA in our case. Once the literature was reviewed, additional scientific analyses of pertinent climate elements were conducted to supplement prior scientific studies.

The patterns and processes identified by the scientific studies were then used to identify potential military impacts. This included in-depth investigations of select missions and weapons systems, accurate tailoring of the science to those missions and weapons systems, and injecting that information into the planning process at the right place and time. This approach was designed to simulate the development of timely, accurate, and relevant DoD climatological products that incorporate smart climatology processes.

The methods developed in this study for determining and coding operational impacts are based on a smart, or modern climatology approach. We applied this process and demonstrated each step through a notional, unclassified non-combatant evacuation operation (NEO) set in the HOA during the autumn (Oct-Nov) of an El Nino year. Complete details on the methods we developed and examples of their application to military operations in the HOA are provided in Chapter III.

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III. RESULTS

A. HOA AND IO PATTERNS AND PROCESSES: LTM, EN, LN, AND THE IOZM

Using the methods described in Chapter II, we developed October-November LTM, composite, and composite anomaly fields for five strong EN, LN, positive IOZM, and negative IOZM periods. Our goal was to address the questions and test the hypotheses described in Chapter I.

We began our analyses by assessing the differences between the EN and positive IOZM composites, and the LN and negative IOZM composites. Comparison of EN versus positive IOZM 850 hPa heights (Figures 17a-d), 200 hPa heights (Figures 18a-d), and precipitation rates (Figures 19a-d) revealed only subtle departures that may be attributed to the single event difference in composite years (see Chapter II). More significant variations were noted in these three key fields, however, when comparing the LN to the negative IOZM composites and composite anomalies. Circulation features common to LN and negative IOZM composites and anomalies in both the 850 hPa (Figures 20a-d) and 200 hPa (Figures 21a-d) height fields are notably stronger in LN than in the companion negative IOZM figures.

Specifically, an 850 hPa anticyclone over the Arabian Peninsula is intensified in the LN composite, and twin cyclones straddling the equator over the eastern IO are deeper in the LN composites and anomalies than in the corresponding negative IOZM composites. Additionally, negative precipitation rate anomalies are much more widespread in the LN composite (Figures 22a-d). Because the EN and positive IOZM composites differ by only one event, and variations in the LN composites appear stronger and more coherent in the mean and from year to year than those in the negative IOZM composites, we confined most of our analysis to the strong EN and LN composite fields.

1. Strong EN Events (1982, 1997, 1972, 1987, 1994)

In the LTM, October-November IO basin SSTs are uniformly warm (above 28ºC), with slightly cooler temperatures near the HOA coastline (Figure 23a). Qualitative inspection of the EN composite reveals a basin-wide 1-2º C warming (Figure 23b), also reflected in the anomaly field (Figure 23c). Note the east-west dipole pattern in the

anomaly field with warm (cold) anomalies in the western (eastern) IO. The cool anomaly can be explained by an extension of anomalously cool waters from the maritime continent into the IO known to occur during EN events (see Chapter II). Additionally, note the warm anomaly extending along the Somali coast (nearly 1˚C) where SSTs are ordinarily coolest. This indicates that the processes that normally create relatively cool SSTs in this region may not be as strong as normal, or are perhaps being counteracted during EN events by competing processes.

Comparison of the LTM and EN composite, and EN anomaly air temperatures (Figures 24a-c) reveals a close correspondence between air temperature and SSTs (Figures 23a-c) across the IO, especially in the warm anomaly fields (Figures 23c and 24c). This suggests that the SSTs are driving the air temperatures and air temperature anomalies. Warm and cool anomalies are observed over land areas as well; however, these cannot be directly explained by the SST anomalies. Explanations for these anomalies are offered later in this section.

In the LTM 850 hPa geopotential heights, the primary features of interest are a strong anticyclone centered over the Arabian Peninsula, twin anticyclones straddling the equator in the eastern IO, and broad troughing over the western IO and HOA (Figure 25a). The EN composite reveals that the Arabian anticyclone is strengthened, the twin anticyclones are filled, and the western IO troughing appears deeper (Figure 25b). The composite anomaly field supports these observations (Figure 25c). The intensification of the western IO and HOA troughing shown in the anomaly field suggests that the processes that normally cause the troughing are enhanced during EN events.

The 850 hPa LTM, EN composite, and EN anomaly vector winds (Figures 26a-c) are consistent with the features described in the corresponding height fields (Figures 25a-c). Broad LTM northeasterly flow originates out of Asia, extending across the Arabian Sea to eastern Africa, which is expected during this transitional period between the Asian summer and winter monsoon periods. The trajectory of this flow over the Arabian Sea suggests the advection of moist air into the HOA. Also evident in the LTM are: (1) westerly equatorial flow across the entire basin (associated with the eastern IO LTM twin

cyclones seen in Figure 25a); (2) a cyclonic circulation in the eastern IO at the mouth of the Bay of Bengal; and (3) relatively strong southern hemisphere easterlies extending across the IO into east Africa.

Flow around the 850 hPa Arabian anticyclone appears to contribute to a relative wind maximum embedded within the broad northeasterly flow along the Arabian coast and into the HOA. For simplicity, we describe this relative wind maximum as the "reverse Somali Jet," or RSJ, as it takes an approximately opposite path to the summertime Somali Jet described by Findlater (1971). Note that the RSJ is stronger than average during EN (Figure 26b-c), over the region of positive SST and air temperature anomalies in the western IO (Figures 23a, 24a). This suggests that anomalously strong coastal downwelling forced by the anomalously strong RSJ near the HOA coast is (at least partially) responsible for the positive SST anomalies. The anomalously strong RSJ also suggests a mechanism for enhanced advection of moist air from the Arabian Sea and IO into the HOA during EN events. The EN composite anomaly an anomalous onshore component in the RSJ directed into the HOA (Figure 26c).

The equatorial westerlies are visibly weaker in the EN composites than in the LTM, consistent with the weakening of the twin cyclones described in the 850 hPa GPH field. This is especially evident in the EN anomaly field, where strong easterly wind anomalies oppose the LTM westerly flow. Additionally, an anomalous, weak cyclonic turning is noted just off the Somali coast, centered at approximately 4N. This anomalous deflection is consistent with anomalously low 850 hPa GPH in the western IO, and with anomalous deep tropospheric warming in this region, driven by anomalously warm SSTs and air temperatures, and resultant deep convection. These anomalous circulations (i.e., cyclonic turning, and stronger and more onshore RSJ, in the western IO, plus weakened equatorial westerlies), coupled with the warmed SSTs and air temperatures in the western IO, and enhanced moisture advection into the HOA, are indicative of positive convection and precipitation anomalies in the HOA during EN periods. Note also that the onshore anomalous vector wind components suggest enhanced upslope flow, which is known to be a forcing mechanism for much of the HOA's coastal region precipitation (see Chapter I).

In the LTM 200 hPa heights field, prominent, twin anticyclones straddle the equator, extending from the tropical Pacific across the IO (Figure 27a). In the EN composite these anticyclones appear weakened, but extend further west across the IO and into the HOA (Figure 27b). This is consistent with weakened convection over the maritime continent known to occur during EN events, coupled with enhanced atmospheric warming described over the western IO and HOA. In the anomaly field, twin anticyclones characteristic of an anomalous Rossby-Kelvin wave pattern are centered over the western IO and eastern Africa, north and south of the equator (Fig. 27c., cf. Matsuno 1966, Gill 1980). The existence of the anomalous Rossby-Kelvin wave pattern suggests a mechanism whereby positive SST and moisture advection anomalies in the western IO generate anomalous convection and atmospheric warming, with the anomalous Rossby-Kelvin pattern being the response to the anomalous warming.

The 200 hPa LTM vector winds show the subtropical jet (STJ) in the extreme north and the tropical easterly jet (TEJ) on the equatorward flanks of the anticyclonic regions centered over the western North Pacific (Figure 28a). In the EN composite (Figure 29b), the TEJ appears weakened (strengthened) over the central IO (western IO and HOA), while the STJ is strengthened over the Arabian Peninsula and shifted southward over north Africa and south Asia. The weakened TEJ over the eastern IO is consistent with the weakened eastern IO 200 hPa anticyclones attributed previously to decreased convection over the maritime continent during EN events. The 200 hPa vector wind anomaly field (Figure 28c) clearly shows the anomalous Rossby-Kelvin response over the western IO and east Africa. The confluence from the anomalous anticyclonic circulation near the equator suggests strengthened upper level easterly flow over the HOA. Flow around the northern hemisphere anomalous Rossby-Kelvin anticyclone contributes to the strengthened and southward shifted STJ over the Arabian Peninsula.

LTM 850 hPa specific humidity (SH) values are generally lower over the HOA than over the IO, but are relatively high over southern Ethiopia (Figure 29a). Close inspection of the EN composite (Figure 29b) reveals an overall specific humidity increase, which is quite striking in the EN composite anomaly field (Figure 29c). This specific humidity increase is consistent with the anomalously warm SSTs and air

temperatures described earlier, as warmed air has an increased capacity to contain water vapor. The positive specific humidity anomalies over the HOA are also consistent with the anomalously onshore wind components described earlier.

LTM 500 hPa map and cross-sectional views of vertical velocity (Figures 30a and 31a) and the corresponding EN composites (Figures 30b and 31b) indicate extensive subsidence over much of the HOA, associated with the descending branch of the HWC. Note that the subsidence pattern is visibly weakened in the EN composite over most of the western IO and HOA (cf. Figures 30a-b). The LTM and EN cross-sections show low level ascent centered at 40E, likely due to surface heating leading to shallow ascent, overlain by middle and upper level descent associated with the HWC. Anomalous low level descent observed at 40E in the EN anomaly figures (Figures 30c and 31c) is probably due to anomalous surface cooling resulting from increased precipitation, which we will discuss in a subsequent set of figures. These anomalies suggest that the descending branch of the HWC over the HOA is weakened during strong EN events as a consequence of anomalously warm (cool) SSTs and air temperatures in the western (eastern) IO resulting in anomalous ascent and convection over the HOA.

Surface precipitation rates are depicted in Figures 32a-c. The LTM and EN composites show average precipitation rates over the HOA ranging from 2-5 mm/day, equivalent to approximately 5-11 inches over the 61 day October-November period. Comparison of the LTM with the EN composite and composite anomaly shows minimum precipitation increases of 0.5 mm/day, with notable 1-2mm/day maximums covering much of Somalia and most of the southern two thirds of Ethiopia. This equates to approximate anomalies ranging from one to five inches (25-40% increases) over the land areas of interest. Additional maximums are observed out over the IO that are larger areally but similar in magnitude. The widespread positive precipitation anomaly is consistent with each of the anomalous mechanisms we described previously. We should note that it is most likely that this precipitation increase is the consequence of multiple convective events scattered throughout October-November, rather than evenly distributed throughout the two months. In an arid region such as the HOA, it is very possible that this anomalous precipitation could result in localized flooding depending upon many

local factors such as soil type and terrain, and temporal distribution of the precipitation,. If multiple precipitation events occur in succession, falling upon already saturated soil, flooding is a likely result.

Analysis of outgoing longwave radiation (OLR, Figures 33a–c) and soil moisture (Figures 34a-c) help to pinpoint regions with maximum anomalous precipitation. Low (high) OLR values indicate increased (decreased) cloudiness, rainfall, and convective activity. OLR differences are difficult to qualitatively assess in the EN composite, but a striking pattern of decreased OLR is evident in the EN mean anomaly figure (Figure 34c). This is consistent with increased convective activity, precipitation, and cloud cover indicated by prior figures. The soil moisture fields (Figures 34a-c) shows that positive anomalies occur over most of the eastern HOA, including much of Somalia and the southern third of Ethiopia. This is consistent with the positive precipitation anomalies and negative OLR anomalies seen in prior figures. The soil moisture anomalies over much of the HOA indicate a soil moisture increase of about 20 percent above the LTM values (cf. Figures 34 a,c).

As discussed in Chapter I, a significant gap in past studies is the lack of schematic representations of anomalous mechanisms associated with HOA and IO precipitation variability. From our analyses of key climate variables (Figures 23-34), we schematically illustrated plausible mechanisms for enhanced HOA autumn precipitation during strong El Nino events (Figure 35). The schematics show how oceanic and atmospheric anomalies are related to each other and together produce greater than average air temperature, specific humidity, upward motion, and precipitation in and near the HOA. The key related circulations are the anomalous upper level anticyclone, strong STJ, low level troughing, strong and onshore oriented RSJ over and near the HOA. A critical organizing circulation for these HOA anomalies is the anomalous Rossby-Kelvin wave that develops over east Africa during strong EN events. This circulation anomaly has not been identified in prior studies of EN or LN impacts on east Africa and the HOA.

2. Strong LN Events (1975, 1973, 1988, 1971, 1974)

Our corresponding analyses of conditions during strong LN events are shown in Figures 36-48. The LTM fields are replicated in these figures to facilitate the analysis of LN deviations from the LTM fields. However, the discussion in this section centers

around LN composite and LN composite anomalies. The SST fields (Figures 36a-c), reveal cooling across much of the IO. The anomaly field reflects an SST dipole with anomalously cool (warm) SSTs in the western (eastern) IO. There are pronounced cool anomalies off the coast of Somalia (-0.5˚C) where SSTs are ordinarily cool. These anomalous SST patterns are approximately opposite to those observed in the EN fields. This suggests that the processes that normally cause relatively cool SSTs in this region are reinforced during strong LN events. This will be examined further in the discussion below of the 850 hPa heights and vector winds.

The surface air temperature fields (Figures 37a-c) show negative anomalies over most of the IO, with the notable exception of the eastern tropical IO. These anomalies, closely match the cool anomalies in the corresponding SST fields (Figure 36c). The overall correspondence between the anomalous SSTs and air temperatures suggests that the SST anomalies are driving the air temperature anomalies, as we noted for strong EN events. Near and along the HOA coast, air temperatures are anomalously cool, while interior HOA temperatures are anomalously warm. The coastal air temperature anomalies are probably induced by close proximity to anomalously cool SSTs. The anomalously warm interior HOA temperatures are induced by processes that cannot be explained by the SST anomalies alone, but will be discussed later in this section.

Examination of the 850 hPa GPH field (Figures 38a–c), reveals that during strong LN events, the twin cyclones over the eastern IO are deepened and the Arabian high is weakened. The LN composite also indicates broad, weak troughing over the western IO and HOA. The deepening of the eastern IO twin cyclones is associated with warmer SSTs and increased convection observed near the maritime continent during LN years. The negative GPH anomalies near the HOA coast are very weak, and less negative than those in the EN composite (Figure 24c). Given that we have thus far observed anomalies in the LN fields approximately opposite to those in the EN fields, we would have expected positive anomalies, indicating increased subsidence. We will discuss this later in this section.

The 850 hPa vector winds (Figures 39a-c) show that during strong LN events, the northeasterly winds over the Gulf of Aden are weaker than average, RSJ has an anomalously offshore component over and near the HOA and the equatorial westerlies spanning the IO are stronger than average. These anomalies are consistent with the weakened 850 hPa Arabian high and deepened eastern IO twin cyclones. Given the orientation of the HOA terrain, the offshore anomalies suggest anomalously dry, continental, downslope flow.

The 200 hPa GPH fields (Figures 40a-c) indicate that during strong LN events, tropical heights are noticeably lower than average from Africa to the maritime continent, but higher than average over extratropical north Africa and central Asia. This indicates a weakening of the subtropical jet over south Asia. The twin anticyclones near the maritime continent are weaker and do not extend as far to the west as average. These anomalies are approximately opposite to those noted for strong EN events (see prior section). However, there is no evidence of an opposite anomalous Rossby-Kelvin response over the east Africa – western IO region (e.g., anomalous cyclones straddling the equator over east Africa).

The chain of reasoning used to explain the Rossby-Kelvin response in the EN composite anomaly apparently cannot be directly applied to the LN case. This may be related to differences in the LN and EN SSTAs --- the magnitude of the western IO cool SST anomalies in the LN composite (about 0.5˚C) is roughly half the magnitude of the warm SST anomalies in the EN composite (about 1.0˚C). Additionally, the height anomalies associated with the twin eastern IO cyclones 850 hPa are much stronger for the LN composite than for the EN composite. This suggests that the strong atmospheric response to anomalous strong convection over the maritime continent during LN events dominates the development of upper level height anomalies, while the reduction of maritime continent convection during EN events allows distinct convection and height anomalies to develop over the east Africa – western IO region. Thus, an anomalous Rossby-Kelvin response at 200 hPa develops in this region during EN events but an equivalent but opposite response does not develop during strong LN events.

The 200 hPa vector wind fields (Figures 41a-c) show an anomalously strong TEJ along and near the equator extending from the maritime continent across the IO. Additionally, the STJ is weaker than average over Asia, especially over southern Iran and Pakistan. .

The 850 hPa specific humidity fields (Figures 42a-c) show anomalously dry conditions over most of the HOA and nearby regions. There is a 1.5 g/kg anomaly minimum centered over eastern Ethiopia, and much of western Somalia. A significant positive anomaly occurs over much of Sudan. These SH anomalies are consistent with the negative SST and surface air temperature anomaly fields (and the implied decrease in the capacity of the atmosphere to hold water), and the anomalously offshore low level wind anomalies over the HOA. Thus, the direct mechanisms for the negative SH anomalies in the HOA during strong LN events are approximately opposite to those during strong EN events.

The omega fields (Figures 43a-c, 44a-c) show that the HOA and western IO is dominated by anomalous subsidence. The low, middle, and upper level vertical motion anomalies are approximately opposite to those in the EN vertical velocity fields, and are consistent with the anomalous SST, wind, surface temperature and moisture patterns combining to decrease convection and precipitation in the HOA and western IO during strong LN events.

The LN precipitation composite and composite anomaly fields show clear evidence of a rainfall deficit over most of the HOA and the northwestern IO (Figures 45a-c). The negative precipitation anomalies range from -1.8 to -0.1 mm per day, which adds up to an anomaly of up to - 4.3 inches over the October-November period. The driest region in the HOA occurs over southern Ethiopia. Since the average October-November precipitation is 7.1 inches in southeast Ethiopia, this represents up to a 60% reduction in precipitation. A deficit of this magnitude is quite significant in an arid region such as the HOA.

The OLR (Figures 46a-c) and soil moisture (Figures 47a-c) anomalies are consistent with the precipitation anomalies over the HOA. In the OLR field, most of the HOA and IO shows positive OLR anomalies, which indicates decreased convective

activity, precipitation, and cloud cover during strong LN events. Negative soil moisture anomalies occur over most of the HOA, consistent with the precipitation deficits for the HOA during strong LN events.

We conclude that the anomalous patterns and processes over the IO and HOA during strong LN events are largely opposite to those during strong EN events, and lead to suppressed rather than enhanced rainfall. Schematic views of the key climate variables that create negative precipitation anomalies in the HOA during strong LN events are shown in Figures 48-49. Coupled ocean-atmosphere anomalies produce lower than average air temperature, specific humidity, upward motion, and precipitation in and near the HOA in October-November. The key related circulations are the anomalous weak STJ, and a weak and offshore oriented RSJ over and near the HOA. The enhanced convection over the maritime continent may be a dominant factor affecting circulation and convection across the IO region, including the western IO and HOA.

B. A PROCESS FOR SMART OPERATIONAL CLIMATOLOGY

To apply the results of our climate variation analyses for the HOA, we developed and tested a process for translating modern climate science into tailored operational impacts. The framework of the process was fashioned from the collective input of mid-level U.S. Air Force (USAF) and U.S. Navy (USN) students enrolled in Naval Postgraduate School (NPS) climatology courses during 2004 and 2005. For our research project, we expanded this framework into a more complete process. The steps in the process are intentionally general to facilitate the application of the process to many different climate variations, regions, and military operations. After developing the process, we tested it in the context of a notional scenario in October-November in the HOA during a strong EN event.

1. Elements of a Smart Military Climatology Product

a. Step One: Identify Customer Formats and Timelines

Step one in the process is to identify customer timelines and formats. Timelines for plan execution range from swift, one-hour operations to months or longer. However, detailed planning for most scenarios is conducted far in advance through the formal planning process, with final details filled in later. Thus, updating pertinent plan annexes with information on climate variations, in the manner discussed here, is a rich

target of opportunity for the METOC community. Nonetheless, situations exist when climate information must be updated very quickly. Knowing exactly when the information is needed lets the METOC officer know how much updating can be accomplished, and how much of the process can be executed. In formal planning, all steps can be executed, while a more rapid planning cycle may mean that only selective steps in the process can be accomplished.

The METOC officer should also ascertain the required format for climate products. Often, climate contributions to a plan are limited to a single page or less, with no figures allowed for illustration. When figures are permitted, they may need to be black and white or gray-scale only, with no color allowed. In some cases, the METOC officer may not be granted a written contribution, but instead be required to furnish oral guidance, or perhaps a table-top briefing to other planners. Personal delivery of the briefing may give the METOC officer the freedom to provide commentary and clarification. However, in some environments, the METOC officer may be passing slides along to operators or intelligence personnel to brief, especially when there is no METOC officer on location or if the METOC staff has other conflicting duties at the time of the operations. This may necessitate that the briefing be a stand-alone document and readily understood by non-METOC personnel.

b. Step Two: Know Plan Elements and Mission Background

The second step is to learn all plan elements and mission background, beginning with the level of operations (e.g., strategic, operational, tactical, etc.). The level of operation dictates the amount of detail required and the types of climate information the METOC officer must acquire to create an accurate climate assessment. The operation could be: a large scale ground, air or naval operation with multiple, complex components; a non-combatant evacuation operation (NEO) a special operations forces (SOF) strike; or anything in between. Learning plan elements and mission background also includes researching the area of interest and learning all routes and destinations. Background information on locations that assets will deploy from or operate out of should be known as well, since climate anomalies at distant locations may prove as important to the overall mission as AOR conditions. For example, a mission

planned for Africa may require tanker support from bases in Europe. Given time, it would be appropriate to also acquire background information from those others locations.

A thorough review of joint and service-specific doctrine and planning guidance will help the METOC officer determine where and when to inject climatology information into the planning process, and where other service counterparts are likely to do the same. Organizations above and below echelon will be involved in planning as well, and coordination among the various METOC staffs ensures conflicting climate assessments are not passed along to decision makers. In operations with significant air assets, multi-service participation is highly likely. The Joint Forces Air Component Commander (JFACC) and his subordinates may be briefed on or have access to climatological data from USAF, USN, and USMC METOC officers in a variety of forums and formats. It is very possible that the data will conflict unless the information is first coordinated.

A review of sister service thresholds and weapons systems limitations is also needed. METOC officers are intimately familiar with their own service's mission limitations and culture, but may not possess that same level of expertise concerning sister services. Learning other services' mission impacts is absolutely vital. This includes determining exactly which platforms will be participating in the operations, and then researching platform and mission thresholds, routes, etc. Many of these thresholds will be codified in joint and service guidance, but much of this guidance conflicts due to operational requirements. The METOC officer also needs to determine how much standard operational impacts are altered by commander-directed rules of engagement (ROE). Commanders have wide latitude to make ROE more or less restrictive, and frequently exercise that latitude.

c. Step Three: Obtain and Assess Resources Required

Once all mission background information and details are known, it is time to obtain and assess the climate resources required for planning. This begins with background research, including a comprehensive review of the literature. The literature review establishes a baseline for LTM climate patterns and processes from which to conduct advanced analysis. It also allows the METOC officer to become knowledgeable on the latest scientific and other technical work, including learning about potential

climate variations. A good place to begin is with a subject bibliography request to AFCCC. However, it will be necessary to consult outside sources as well (e.g., online and printed scholarly journals, climate web sites, etc.)

In this data gathering phase, the METOC officer should determine what data and products DoD climate centers such as AFCCC can provide. AFCCC archives a wide variety of LTM data in diverse formats (e.g., text-based, graphics, online, compact disc, etc.), and they can often very quickly acquire specialized data not on hand at the time of the request. Pre-existing formal and informal climate products created by other operational METOC units should also be sought out, validated, and leveraged. For example, Standard Operating Procedures (SOPs) and Terminal Area Forecaster Reference Notebooks (TFRNs) will include key climate information and rules of thumb for operating areas and bases. Operational Weather Squadrons (OWSs) have produced many classified and unclassified theater-specific climatology briefings, as has the AFOG. Most plans will already contain a METOC annex to address climate impacts, albeit from the LTM perspective.

Gaps exist in DoD climatological products, particularly with respect to current information on climate variations and climate forecasting. Much of the gap can be filled through the literature review, but further augmentation can come through leveraging products from credible U.S. and civilian climate organizations. Long range climate forecasts and information on climate variations are furnished online by several civilian operational climate organizations, including the NOAA Climate Diagnostics Center (CDC 2006), the Climate Prediction Center (CPC 2006), the International Research Institute for Climate and Society (IRI 2006), and the Australian Bureau of Meteorology (BOM 2006).

These products and data will prove extremely beneficial to the METOC planner, but like any tool, should be used wisely. First, it is entirely possible that pre-existing operational climate information mentioned is outdated or inaccurate. This information should be cross-checked for currency and accuracy, and updated as appropriate. Additionally, the METOC officer must always consider classification issues

to avoid compromising the mission. Even a simple web search for climate information could be monitored by foreign governments or terrorist organizations and tip them off to an impending operation.

d. Step Four: Assess Climate System

Once climate and operational background information are compiled and assessed, it is helpful to organize key information in checklist fashion. This mission specific checklist need not be formal; it can be hand written, or even computerized. The checklist helps to organize thoughts and ensure all relevant information is considered during the climate assessment. The mission specific checklist includes a listing of the overarching operations and sub-missions, key operational considerations for each of these missions, and specific climate features that should be assessed. An example of a mission-specific checklist is provided in Figure 53 and discussed in Part C of this chapter in the context of our example operational scenario.

When assessing the climate system, the importance of understanding LTM climate patterns, processes, and controls cannot be overemphasized. This includes knowing relative locations of key features such as semi-permanent pressure systems, as well as comprehending known local effects (e.g., those associated with terrain or proximity to coasts or large bodies of water, etc.). METOC planners should also determine their confidence in LTM data. LTM studies and information compiled and produced by AFCCC are ordinarily comprehensive, but may not be at the resolution needed. It is also unlikely these studies are sufficiently tailored to the level of operation. Finally, the period of record (POR) must be analyzed for any unusual events (e.g., sustained drought or flooding) that could bias the data.

There may be additional known weaknesses in the dataset that render it unreliable. For instance, it has been demonstrated that ACMES data may be suspect for certain regions of the world (Feckter and Applequist 2005). METOC officers often use climate data from a nearby reporting station to estimate climate effects at a given location, especially in data sparse regions where DoD operations are commonly executed. However, terrain effects may render these sorts of estimates unreliable or unrepresentative. One must also consider that data in many countries is likely to be inaccurate to some degree due to poorly maintained observing equipment or inconsistent

reporting procedures. There are frequently significant temporal gaps in the data as well. Finally, pertinent data and information may be scattered throughout multiple locations and publications, and require consolidation prior to use.

The METOC officer should identify relevant recent, ongoing, and predicted climate variations that have occurred or may occur at the time and place of operations. Intraseasonal, interannual, and decadal variations (e.g., ENLN, NAO, MJO, IOZM, etc.) should all be considered. Much of this information will come from the background literature search. The civilian climate monitoring and prediction sites provided previously are good sources to consult. The METOC officer should consider recent and on-going trends (e.g., recent warming or cooling, droughts or heavy precipitation, etc.). Episodic or one-time events (e.g., tropical cyclones, floods, volcanic activity, tsunamis, anthropogenic changes, earthquakes, etc.) can cause environmental mission impacts well beyond the actual time of occurrence. The occurrence of climate variations does not necessarily mean significant environmental impacts will result. The impacts can be very sensitive to the magnitude of the variation, and to the location and time of year. For example, ENLN and the IOZM can have major impacts on the HOA autumn short rains, but little effect on other seasons.

Finally, media reports can be a good source for information on recent environmental events in any particular area of interest. Intelligence directorates at unified commands track and brief environmental issues obtained through open and classified sources. METOC officers on unified command staffs will find this information extremely valuable in building climate scale impacts assessments. This information can and should be passed along to subordinate organizations that lack robust intelligence support.

A useful method to assess LTMs and the impact of climate variations is through the compositing approach employed in this research. Although we used a more advanced programming package, this analysis is readily accomplished through online tools at the CDC website. The LTMs allows one to establish a climate baseline for important variables, confirm that the data is appropriate for the problem, and validate what was learned about LTM patterns and processes in the literature review. Side-by-

side comparisons of the LTM composite with composite and composite anomalies for a given climate variation facilitates qualitative and quantitative assessments of anomalous climate processes, which can then be tailored to operationally relevant climatology impacts and products. The technique allows the METOC officer to identify and highlight impending or in-progress climate variations likely to impact operations

Advanced statistical and dynamical methods (beyond the simple compositing techniques employed and described in this thesis) must be considered as well. Much of this advanced climate work is clearly beyond the current training or resources of small operational METOC units and planning staffs, so use of these techniques is not discussed here. However, many advanced climate products are readily available through the web sites of the civilian academic and governmental organizations cited earlier, and many others. Given enough advance notice in the planning cycle, the METOC officer can task AFCCC or other centralized DoD climate organizations for this sort of information. However, these organizations have not traditionally conducted research of this type. This is a clear void that must be filled, either through the stated requirements process or through the academic community.

e. Step Five: Apply the Science to Operational Impacts

Tailoring climatological information to operational impacts is the culmination of our smart climatology process. Good science is for naught if end users cannot understand the products, or if the METOC officer fails to correctly assess requirements, missions, and weapons systems to be employed. Success requires close contact with operators throughout the planning process and operational cycle. Providing the information to operational users in overly scientific or vague jargon may hinder the decision cycle more than it helps. For example, informing the commander that Addis Ababa, Ethiopia received 30 mm of rain during October is not informative enough, and much less than the METOC officer can provide. Alternatively, the METOC officer could use the process we have described above to brief the commander that: (1) a strong EN event is in progress; (2) the region around Addis Ababa has experienced flooding in the last two months; (3) past El Nino years have averaged a 50% increase in rainfall; and (4) that this rainfall comes in the form of increased thunderstorm activity. This will inform the commander that: (1) the potential exists for flooding during the time of the operation,

and (2) the prior environmental assessment (based on LTMs) in which conditions were deemed favorable for the operation might now have to be revised (in light of the recent and expected future anomalies) such that the conditions must now be considered moderate or unfavorable for the operation.

State of the science climate forecasts are general forecasts, and are not meant to be predictions for specific times and locations (e.g., individual days and microscale regions). However, it is within the METOC officer's capability to provide useful assessments of the tendency or likelihood of climate variations to impact any given operation using the smart climatology process developed and applied in our study. Using rainfall as an example, the METOC officer can determine the mean precipitation amount using the NCEP reanalysis composites and station records if available. If the METOC officer determines through his climate system assessment that EN conditions are likely, the compositing process can be repeated for strong EN events, as we have done. Then, the difference between the two can be computed and used to assess the magnitude of the difference between the LTM and EN events. Qualitative assessments are possible using this technique as well. For example, a climate variation may cause a precipitation maximum to shift from one location to another. This may mean improved operational conditions for one area of concern, but deteriorated conditions for another. This information can be incorporated into the overall assessment.

The tendency approach is far from perfect, but it is grounded in firm science and provides much more useful information to the operational commander on climate variations than what is currently provided. Using this technique allows the METOC planner to more clearly characterize the extremes that are of most importance to military operations. Tendency assessments are a step forward, an evolutionary move towards more in-depth assessments through smart, or modern, climatology techniques. Limitations and shortcomings exist, however. For example precipitation rate is a reasonably accurate field in the NCEP Reanalysis. However, complementary information on soil types for specific locations is likely unavailable to METOC officers. Thus, it may be difficult to provide a complete and accurate assessment of the impacts of precipitation variations on ground operations. Combining the science findings with what is known

operationally allows the METOC officer to make useful tendency assessments. Examples of tendency assessments are provided in the scenario we present in Part C \of this chapter (Figures 54-56).

Whenever possible in this tailoring process, the METOC officer should consider clarifying what climatology information can and cannot do for operational planners, and how a climate assessment is much different from the short-term weather forecasts that customers are more used to seeing. The key idea here is that climatological information can be used to anticipate the future, as is done with weather forecasts. However, climatology-based forecasts are inherently more general since they are based on averages. So, as an additional example, climatology data may predict winds from the northeast for a given location during the first week of January, but this should not be taken as a forecast of winds from the northeast on every day in the first week of January.

Finally, the METOC officer may consider incorporating historical case studies, or vignettes from historical cases to clarify key points (e.g., cases in which good climatology information allowed planners to manage environmental risks and/or exploit environmental opportunities, or caused mission failure). It is very likely that some useful examples will turn up in the research phase of the smart climatology process. Also, some recent examples may be provided by operators and used to remind the audience of the importance of climatological information.

f. Step Six: Verification and Assessment

Missions, ROE, and other operational details may change at any point in the planning cycle. The METOC officer must review products frequently, assess their accuracy and usefulness to the operator, and update whenever possible. Part of this step is to continuously seek feedback from end-users. This feedback should come from operational users as well as other METOC personnel. Depending upon the speed of the planning cycle, the METOC officer may not be able to incorporate changes immediately. For example, deliberate plans are only reviewed every two years, so few opportunities exist for formal corrections. Crisis action planning is a rapid and fluid process, and events may transpire before an opportunity is presented to make corrections. This highlights the importance of anticipating and creating climate assessments in advance.

The process described above is illustrated in flowchart format in Figure 49. This flowchart may help the reader understand how each step fits into the overall process. Additionally, we provide a checklist for this process in Figure 50. This checklist contains an abbreviated version of all the steps and major sub-steps in the smart climatology process. We hope that METOC planners will reproduce this checklist and use it to help organize thoughts when creating operational climatology products.

g. General Guidelines

There are a few general guidelines to impart that don not cleanly fit in any of the six steps. First, always provide names and contact information for key people who created the product. Date all documents prepared, cite all sources on slides or figure for each key piece of information shown, and reference the location of the source data. This gives credit where credit is due, but also facilitates future updates or corrections. Describe intent, motivations, assumptions, and qualifiers for the product, preferably right up front. If the product is intended solely for a METOC audience, state this. The METOC officer should always keep end-users' backgrounds and requirements in mind when selecting the type and level of information to include in the product. Consider including space weather and climate issues. Often times, operational users fail to realize that solar flare activity can impact communications equipment, for example. A collection of useful links on space weather can be found on the AFWA Space Weather web page (AFWA 2006).

C. EMPLOYING THE RESULTS OF THIS STUDY

We have critiqued the current state of military operational climatology, and developed a process to guide METOC personnel in the production of improved, tailored climatological products. We call this the smart climatology process for developing climatological support for military operations. As a proof of concept, we tested our six-step process in a plausible, unclassified, notional operational scenario. In the scenario, the U.S. Central Command (USCENTCOM) staff determines that political instability and civil unrest in Ethiopia may necessitate the evacuation of personnel from the U.S. Embassy in Addis Ababa sometime during the autumn. The staff is ordered to update their standing noncombatant evacuation operation (NEO) plan to prepare for this likelihood.

As part of the planning process, an Air Force METOC officer is tasked to provide a climate assessment. Armed with our HOA study, he decides to employ the smart climatology process to generate improved climatological planning products. He uses the checklist provided in Figure 50 to guide him in his climate assessment. In order to keep the following discussion at the unclassified level, the NEO details and descriptions are heavily paraphrased from JP3-07.5, "Joint Tactics, Techniques, and Procedures for Noncombatant and Evacuation Operations." Similarly, we derive operational impacts criteria from JP3-59, "Joint Doctrine Tactics, Techniques, and Procedures for Meteorological and Oceanographic Support," and the JMH (USJFCOM 2002).

Recall that step one is to "Identify Customer Formats and Timelines." In our scenario, it is currently July. When asked, the plans shop informs the METOC officer that he has two weeks to craft a brief assessment for a NEO projected to execute sometime in October-November (about ninety to one hundred days out). Timelines for the actual execution of the operation are likely to be much shorter, but this is an entirely plausible timeline for planning activities. In this scenario, we assume that the operational planning community is acting on accurate, advance intelligence to put a plan into place well in advance of any operation. The initial, required format is a half-page, text-only appendix for a contingency plan.

As part of his regular staff duties, the METOC officer knows that this operation will be a topic of high interest. He will be required to brief METOC impacts formally to senior leadership, and informally to any number of fellow Action Officers (AOs) in various staff directorates to include, but not limited to Operations (J3), Intelligence (J2), and Logistics (J4). In addition, the METOC officer must coordinate this assessment with Joint Staff counterparts and subordinate METOC units, particularly the METOC unit designated to take the lead in the operation. With low manning in the METOC shop and many climatology requests to satisfy, the optimal approach to fulfill these diverse requirements is to create and maintain a small, standardized set of clearly annotated impacts matrices that can be briefed selectively, depending upon the recipient of the information.

Step two is "Learn Plan Elements and Mission Background." The METOC officer has never participated in planning for a NEO, so he is directed to review JP3-07.5 for general details. Directly from this publication he finds that a NEO is conducted to evacuate "noncombatants, nonessential military personnel, selected host-nation citizens, and third country nationals whose lives are in danger from locations in a host foreign nation to an appropriate safe haven and/or the United States." He also discovers that "NEOs usually involve swift insertions of a force, temporary occupation of an objective, and a planned withdrawal upon completion of the mission." From this information and subsequent discussions with fellow staffers, the METOC officer realizes that a NEO is highly tactical in nature. However, NEO planning is highly complex, requiring considerable planning and coordination through multiple command echelons.

He immediately begins to coordinate with fellow AOs to assemble elements of the plan necessary to create accurate climatology products. From his level on the USCENTCOM staff, the METOC staff officer will primarily supply climate information to senior decision makers, fellow AOs, and other METOC organizations, which necessitates a broad look at the missions. At the execution level, it is likely that subordinate METOC organizations will further tailor his assessments, but coordinate any changes. The NEO will be executed to evacuate U.S. citizens from the U.S. embassy in Addis Ababa, Ethiopia. Staff numbering 150 and an approximately equal number of U.S. expatriates from the surrounding area will be airlifted to Camp Lemonier, Djibouti prior to transport back to the United States. All personnel and assets utilized are part of an on-call, quick-reaction team based at Camp Lemonier by USCENTCOM for this type of operation.

The plan specifies that the evacuees will be transported out of Addis Ababa using C-17A Globemaster III aircraft. The C-17As are home-based out of Ramstein AB, but will be staged out of Camp Lemonier for the duration of the operation. Logisticians inform the METOC officer that the unrefueled range of a C-17A is approximately 2,400 nautical miles, so no air-refueling capability is required for the mission. The aircraft has a passenger capacity of 100, so it is anticipated that six missions will be required over the course of fourteen days. The first and last missions are for military personnel and equipment used to plan and conduct the NEO, while the middle four are designated for

evacuees. Also employed for the mission is an HH-60G Pave Hawk rescue helicopter. This rotary wing asset will be utilized for emergency medical evacuation and relocating evacuees from isolated locations in and around Addis Ababa to the U.S. embassy for evacuation, if necessary.

Before and during the operation, overhead intelligence will be collected using RQ1B Predator Unmanned Aerial Vehicles (UAVs) operating out of Camp Lemonier. Intelligence personnel will also utilize data from reconnaissance satellites, so accurate assessments of cloud cover are extremely important. Finally, evacuees and military personnel will be transported in and around Addis Ababa as required using embassy-owned vehicles. The embassy's Marine Corps detachment has two Highly Mobile Multi-Wheeled Vehicles (HMMWVs) on site at the embassy. A forty-passenger bus and several sedans are also at the disposal of the evacuation team.

From the planning details gathered thus far, the METOC officer knows that he will need to obtain and assess climate information for Camp Lemonier and the area around the embassy, at a minimum. Fortunately, a highly detailed information pamphlet known as a NEOPACK (Non-combatant Evacuation Operation Packet) is available from the J2 and other planners (JP3-07.5). From JP3-07.5, a NEOPACK is a "preassembled package of selected maps, charts, and other geographic materials of various scales to support the planning and conduct of noncombatant evacuation operations in selected countries or areas." The NEOPACK also contains additional specific, detailed information on potential NEOs for the Addis Ababa area. This will prove quite useful to the METOC officer as he prepares his assessments. Examples of the sorts of terrain maps that the METOC officer obtained from the NEOPACK are shown in Figure 51.

A telephone call from an operational plans officer, coupled with a review of the NEO CONPLAN, reminds the METOC officer that his brief, text-only input belongs in Annex H (METOC) of the plan. A review of JP 3-59 and the JMH, however, reminds the METOC officer that climatological input may also be required in additional annexes, for which others are responsible. While this input is similar in format, it will be fed into the plan through a different chain of fellow AOs, so there will be subtle differences in the end product. Further review of the evolving operational plan reveals that U.S. Special

Operations Command-Central (USSOCCENT, USCENTCOM's special operations component) is charged with plan execution. USSOCCENT's small, three-person METOC office deployed to Camp Lemonier, Djibouti will need to be consulted throughout the planning process.

From discussions with other AOs and his review of the plan, he knows that all C17 evacuation missions will operate out of Camp Lemonier. Most ground operations will be coordinated and conducted under the direction of the embassy's Marine Corps detachment. Given the multi-service nature of the operation, the METOC officer consults his smart climatology checklist and is reminded to research service specific guidance so as to become more familiar with sister service mission impacts. Fortunately, a Marine Corps non-commissioned officer is part of the small METOC staff at Camp Lemonier, and the current Senior METOC Officer (SMO) at USCENTCOM is a Navy 05 with substantial experience providing climatological planning support for Marine Corps operations. This additional expertise complements the background of the USAF O3 METOC Officer.

Once the METOC officer knows the participating forces and commands, he consults with the various METOC staffs to learn and standardize general mission impacts. For the purposes of this scenario, impacts criteria are derived from JP 3-59 and the JMH. In real-world operations, these rather general impacts would be adjusted and fine-tuned to reflect commander-directed ROE. The METOC officer would likely maintain a spreadsheet produced in-house with more specific, classified criteria for select operations, and disseminate updates to other METOC users. Impacts criteria for missions included in this scenario are in Figure 52.

Step three is "Obtain and Assess Data and Resources Required," which includes conducting background climate research. Unfortunately in this case, there are no preexisting SOPs or TFRNs to glean information from. The METOC officer does possess a well-tailored Ethiopia briefing produced by the Air Force Operations Group (AFOG) which contains information on terrain to supplement the NEOPACK, as well as detailed information on the LTM climate of the region around Addis Ababa. The METOC officer also conducts a review of the scientific literature. He determines that

strong EN (LN) events usually mean wetter (drier) than normal conditions for the HOA, and that these conditions are likely intensified when coupled with positive (negative) IOZM event. He uncovers no additional conclusive research that would allow him to make further, credible operational climate assessments. He thus decides that he will focus on these climate variations when he begins his actual assessment.

The next sub-item in this checklist step is to determine what data DoD organizations can provide. He knows that AFCCC published a DVD-ROM in 2005 with material relevant to Southwest Asia LTM climate, including plain language narratives, operational climatic data summaries (OCDSs) for all reporting stations in the region, and regional climate guides by Vojtesak et al. (1990) and Giese (2004 and 2005). The METOC officer decides to use the assets on this DVD-ROM for his climate assessments, but knows that he must double-check the AFCCC world wide web site to determine if this data has been updated recently prior to using it for the impacts assessment.

He knows that DoD sources lack information on climate variations and climate forecasting in particular. Since no DoD organizations do climate forecasting, the METOC officer consults a list of civilian climate sites he has previously compiled. He finds that concurrent, strong EN and positive IOZM events have been forecasted to be in effect at the projected time of operations. Below are the main world wide web sites consulted:

1. CDC El Nino Southern Oscillation Diagnostic Discussion (CDC, 2006): This site provides useful discussion on the current state of El Nino and La Nina events.
2. IRI (IRI 2006) Map Room Regional Monitoring: This site furnishes current anomalies for temperature, precipitation and select atmospheric circulation features for a number of regions around the globe.
3. Indian Ocean Dipole Homepage (Behera 2006): This web page furnishes the latest details on the state of the IOZM.

Confident that he has gathered all necessary background information, the METOC officer knows that it is time to move forward to the fourth step of the process, "Assess Climate System for Time of Operation." Before conducting any in-depth climate analysis, he drafts the suggested mission specific checklist in order to help him organize

his thoughts and focus on relevant aspects of the climate system and potential military impacts. His checklist would likely be handwritten, but we provide a table with this information for clarity (Figure 53).

Next, he must determine the LTM climatology, and assess confidence in that information. Bringing all the LTM climate and military resources he has gathered to bear (e.g., AFCCC narratives, DVD-ROM, climate literature, compositing, etc.), the METOC officer characterizes the LTM climatology in and around Addis Ababa and Djibouti. Reporting stations near Addis Ababa are few, but have been manned continuously. From a quality standpoint, the LTM data from AFCCC is deemed representative and adequate, as are all briefings and literature. It is not a perfect situation, but this LTM data is the best the METOC officer has to work with. The LTM climate in and around Djibouti appears to present no problems for NEO operations. The rainy season is mild and brief, and skies are generally clear, except for patchy, overnight clouds that occasionally last into mid-morning. Isolated rain showers occur in late October through early November. Winds are generally light, and controlled by the cycle of the land-sea breeze.

In brief, the primary weather features impacting Addis Ababa during October–November are associated with localized thunderstorm activity. Although thunderstorms occur on station on just 4-5 days each in October and November, thunderstorm activity is observed over the nearby mountains on most days from October through mid-November. Mean cloud cover is scattered in each month, but multi-level cloud cover associated with the thunderstorm activity drifts over the Addis Ababa area on most days. Ceilings below 25,000 feet occur 20 percent (15 percent) of the time most of the day in October (November) and 40-45 percent (25-30%) of the time from 1200-1700 local time. Mean monthly rainfall is 0.9 inch (23 mm) in October and 0.6 inches (15 mm) in November. However, extremes of 10.7 inches (3.8 inches) have been noted in October (November). It is the extremes that the METOC officer must keep in mind when exploring climate variations later on.

Once the LTM climate is established, the METOC officer attempts to identify relevant recent, ongoing, and predicted climate variations. As mentioned earlier, the METOC officer established through his literature review that ENLN and the IOZM

events are the primary climate variations to consider. His review of key civilian organization climate forecasting websites reveals that strong EN and positive IOZM events are underway, which heralds significant operational impacts for the autumn. He has also learned from the J2 AO and his review of open source news reports that the spring rainy season was unusually cloudy and rainy, (200% of the normal rainfall) and that these conditions are persisting into the early summer. He knows this is characteristic of EN events for this region, and takes this information under advisement. If the wet trend continues into the fall, significant operational issues could result, primarily for trafficability and overhead collections, so he will take this into account as he prepares his impacts assessments.

Next, the METOC officer turns to the CDC web site to do composite analyses of the LTM, strong EN composite, and strong EN composite anomalies (NOAA 2006). This helps him identify characteristic patterns, processes, and mechanisms to assess during strong EN events. The results of this composting approach are described in Section A of this chapter, and need not be repeated here. He also briefly considers more advanced statistical and dynamical methods, but this is beyond his training and the short timeline he has to complete his assessment. He knows that many civilian organizations use advanced methods in their climate assessments, so leveraging their assessments will have to do for now. In anticipation of updating his products for future use, he decides to submit a formal request to AFCCC for an assessment of HOA climate during EN and LN events. If AFCCC is unable to accomplish this task, the submission may provide them with support for requesting resources to conduct these types of assessments in the future. He also makes a note to himself to forward his request for advanced climate studies to the Air Staff for possible incorporation into future AFW thesis lists.

Step five is “Tailor the Science to Operational Impacts.” His tailoring will be in the standard, color-coded impacts matrix format operators are used to seeing, but he will incorporate a tendency assessment, as described previously, to alert operational users to conditions that are likely to be better or worse than normal. Recall that the primary airframe to transport military personnel and evacuees is the C-17A Globemaster III. HH-60G Pave Hawk helicopters will be on-station to support emergency aeromedical evacuations and small passenger loads from in and around Addis Ababa to the embassy.

Predator UAVs will provide continuous, 24-hour surveillance of the area and relay intelligence imagery back to a command center in Djibouti. A 40-passenger bus, Highly Mobile Multi-Wheeled Vehicles (HMMWVs), and several sedans owned by the embassy will be used as required to transport U.S. citizens from various locations to the embassy for evacuation.

Climate impacts matrices for NEO scenario operations and sub-missions are provided in Figures 55-56. Column one of each matrix lists the specific operation assessed. The second column presents impacts assessed from LTM data for a typical year. Establishing typical impacts from LTM data and the literature review provides a point of departure from which operational users can comprehend the tendency assessments provided for EN (LN) in column three (four). Although the scenario assumes EN conditions are in effect, LN impacts are provided here as well. With the research on both EN and LN completed, documenting these findings in anticipation of very likely, future operations in the HOA is recommended. In practice, it's likely that the METOC officer would remove the extraneous LN information (if EN conditions are predicted) from the impacts chart in order to avoid ambiguity and confusion.

The color coding in the impacts matrices is a standard convention used in military channels for climate impacts assessments, and well understood by operators. Impacts are coded green (favorable), amber (marginal), red (unfavorable) and white (no change) as depicted in the legend. Shading from one color to another denotes a transition from one condition to another over the climate forecast period, for example from amber (moderate) to favorable (green). Shading with a secondary color superimposed on a more predominant color indicates that one climate condition is expected to be prevalent, with a secondary intermittent or occasional condition likely as well. Where possible, all impacts as well as transitional shadings are briefly clarified in the text box below the matrix.

Air operations impacts are provided in Figure 54. For the LTM, the assessment for both C-17A and helicopter operations is for mostly favorable operational impacts, with occasional impacts from thunderstorm activity in and around Addis Ababa. Conditions are expected to improve to favorable overall by late October on the termination of the short rains. EN conditions are expected for the period of the operation

and the results of his climate evaluation in earlier steps leads the METOC officer to anticipate increased precipitation, thunderstorms, and cloud cover for the projected period of the operation. Therefore, the EN assessment is crafted to indicate a tendency towards moderate, occasionally unfavorable impacts until late November, especially during the afternoons.

Review of the impacts criteria for RQ1B Predator operations (Figure 52) reveals that UAV airframe and mission limitations and thresholds are far more restrictive than those outlined for other air operations. The impacts matrix for this mission is in Figure 55. Launch and recovery provide little concern because LTM, LN, and EN conditions are expected to be overall benign, resulting in mostly favorable impacts. At worst, it is possible that afternoon maximum temperatures may tend to occasionally exceed operational limitations for Predator operations at Camp Lemonier during typical and LN conditions. Mission thresholds are a different matter. The presence of increased precipitation and thunderstorm activity in the vicinity of Addis Ababa during EN conditions indicates increased cloud cover that will degrade the tendency assessment to moderate to occasionally unfavorable. During LN conditions, conditions for Predator operations will tend toward favorable, with occasional moderate impacts. Satellite collections do not have the airframe limitations of other ISR assets, but they are also limited by cloud cover. Typical or LTM conditions are assessed as moderate overall, primarily for afternoons due to cloud cover. Impacts will tend toward moderate and occasionally unfavorable during EN events.

The Ground Operations impacts matrix in Figure 56 includes assessments for trafficability and personnel comfort. Although road conditions are poor at many locations around Addis Ababa, the main routes expected to be utilized are not in complete disrepair. LTM conditions for trafficability are assessed as overall favorable, occasionally moderate. For EN, the increased rainfall and thunderstorms make conditions overall moderate. During strong La Nina events, the lack of rainfall is expected to make the trafficability assessment tend towards favorable, or better than the LTM. Personnel impacts closely mirror the assessment for trafficability. Temperatures in the autumn in and around Addis Ababa are mild, and it is not expected that troops or evacuees will be exposed to the elements.

Once all the tailoring is complete, step six of the process directs the METOC officer to seek out feedback and verify the accuracy and validity of the assessments made. He knows to follow up on the information in the weeks and months leading up to, during and after the NEO execution, and to seek out opportunities to update the assessment as required. He also knows that many NEOs and other operations are planned for this part of the world, so the lessons captured here need to be incorporated into future climate products. Perhaps some erroneous assumptions made by operational users and others can be caught and rectified before the operations commences.

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IV. SUMMARY AND CONCLUSIONS

A. SUMMARY

We have critiqued the current state of military climatology with an emphasis on operational planning and the impacts of climate variations on military operations. The MEI and the DMI were used to identify the five strongest EN, LN, positive IOZM, and negative IOZM events over the 30-year period 1969-2005. These five strongest events were used to create five-year EN, LN, and IOZM composites of key NCEP reanalysis climate variables. Analyses of these composites at a two-month scale allowed us to determine mechanisms by which EN and LN events in the tropical Pacific extend their effects into the IO. Our scientific findings were translated for use in warfighter impacts assessments. To do so, we developed a six-step process for METOC personnel to create, or update existing, climatology products using a modern, or smart, climatology approach. As a proof of concept, we applied this process to a notional, unclassified NEO set in the HOA during the autumn short rains season (October-November).

B. ENLN IMPACTS ON HOA PRECIPITATION VARIABILITY

We identified mechanisms for enhanced (suppressed) HOA autumn precipitation concurrent with strong EN (LN) events. Principal anomalies during EN events include:

1. Warm SSTAs across most of the IO, especially off the HOA coast.
2. Anomalously warm, moist air across most of the IO basin, likely a response to the warm SSTs.
3. Anomalously low (high) 850 hPa (200 hPa) heights over the HOA and western IO, indicative of anomalous deep tropospheric warming, ascent, and convection.
4. Anomalous Rossby-Kelvin wave response over western IO and HOA.
5. Anomalous onshore advection of moist air into the HOA.
6. Anomalous HOA precipitation.

We concluded that anomalous patterns and processes over the IO and HOA concurrent with strong LN events are largely opposite to those observed during EN events. The notable exception is the absence of an equivalent (but opposite) Rossby-Kelvin wave response over the western IO and HOA. We speculated that the increased convection known to occur over the maritime continent during LN events (due to a

westward shift of the equatorial warm pool) is vigorous enough to overwhelm convection and related Rossby-Kelvin wave anomalies over the western IO and HOA.

C. SMART, OR MODERN, CLIMATOLOGY PROCESS

The primary objective of this study was to critique the current state of military operational climatology and provide suggestions for improvement. We concluded that most standard DoD climate products do not reflect modern climate analysis and forecasting techniques --- in particular, they do not account for climate variations. We developed a process to guide METOC personnel in the production of improved, tailored climatological products: a process we call smart climatology. One of the aims of smart climatology is to characterize climate mechanisms, patterns, and processes in a manner that facilitates their use in developing climatological products for use in military planning. To realize this goal, we identified and schematically illustrated the anomalous mechanisms responsible for precipitation variability in the HOA. We then translated the science for operational missions, and tailored these findings into warfighter impacts using a convention we label tendency assessment. These assessments help account for climate extremes brought about by climate variations. The tendency assessment is illustrated in a format familiar to operational users.

D. CONTRIBUTIONS OF THIS STUDY

Many prior scientific studies have explored the impacts of EN and LN events on precipitation variability in the HOA. We confirmed findings from these prior studies, and developed additional new findings about impacts and impact mechanisms. Our study is unique in many aspects. For example, unlike many past HOA studies we:

1. examined mechanisms for HOA precipitation variability during five EN events and five LN events that occurred over 30 years, rather than just a few events that occurred over shorter periods.
2. used a Pacific-wide, multivariate index to identify EN and LN events, rather than a regional and/or single-variable index.
3. focused exclusively on events that occurred after the beginning of the satellite era.
4. used global reanalysis fields that were not used for most prior HOA studies.
5. used compositing techniques to estimate characteristic patterns during EN and LN events, rather than the case study approach.

6. examined the mechanisms by which EN and LN events influence precipitation variability in the western IO and HOA, rather than just statistical relationships between EN and LN events and single-variable ENLN indices.

There are few formal studies specifically on the topic of applied military climatology for the HOA. Even fewer address applied military climatology from a modern, or smart, perspective. Our study is among the first to do so, and its unique contributions to military climatology include:

1. a critique of the current state of operational military climatology products.
2. development and application of a smart climatology process for developing military climatology products
3. development and application of the anomaly tendency concept to characterize climate extremes in a manner meaningful to military operational users.
4. schematic illustrations of anomalous patterns, processes, and mechanisms associated with EN and LN events in a manner designed to be useful to military meteorologists.

Our approaches allowed us to make significant contributions to climatology, military operations, and the nexus of the two. Our finding that HOA autumn precipitation is enhanced (suppressed) during strong El Nino (La Nina) events is not new, but the combination of data and methods used in this study helped confirm results of past studies, clarify the mechanisms for these precipitation variations, and distinguish EN processes from LN processes. The smart climatology process allowed us to translate science to operational art. Finally, the tendency assessment convention allowed us to present military climatological impacts in a manner not done previously.

E. RECOMMENDATIONS FOR FUTURE RESEARCH

The prototype impacts tendency assessments we drafted for the NEO scenario were intended to demonstrate the key concepts of our methodology. They were kept general by design in order to keep this thesis in the unclassified realm. We recommend that future researchers use more detailed and specific operational impacts criteria and complementary datasets to further tailor the products presented in this thesis. We also recommend that the impacts assessments be expanded to include additional missions and

weapons systems. Our scenario was developed to test the six-step process. The next logical step would be to update real-world climatology planning products for current operational plans.

We recommend that the process presented here be replicated for other areas, beginning with regions of elevated DoD interest. Ford (2000), Hildebrand (2001), Feldmeier (2005), Stepanek (2006), and Vorhees (2006) all employed smart, or modern, climatology approaches to analyze climate variations in regions of DoD interest. Each of these studies is an excellent candidate for extension to military applicability using the six-step smart climatology process we outline in this thesis. Additionally, we recommend that select products from AFCCC's extensive database of LTM products be updated with information on climate variations, using our process. Key candidate products we suggest are plain language narratives and other text-based data. Operators and METOC users alike are accustomed to this widely-used narrative format, making this an excellent point of departure for future modernization of additional DoD products. Finally, the AFOG briefings we discussed are highly operationally focused, and would benefit greatly from modern climate science updates.

Our analysis was limited to compositing of reanalysis data, which is but one component of the smart, or modern, climatology approach. We recommend that future researchers explore the additional advanced climatology techniques we described to update this and other products. For example, downscaled reanalysis data, advanced statistical methods, and modeling and simulation approaches are all smart climatology methods that complement the compositing work we accomplished. A recent, informal study by Feckter and Applequist (2005) revealed that ACMES data is flawed for key variables in militarily critical parts of east Asia. We recommend that ACMES data be tested for the HOA as well to establish whether these flaws extend to other regions of the globe.

We recommend that this study be expanded to include additional datasets beyond the reanalysis data we utilized. We considered incorporating cloud data from the International Satellite Cloud Climatology Project (ISCCP), for example, but were unable to do so within the scope and time constraints of this thesis work. The inclusion of cloud

data would have allowed us to further refine our ISR impacts, for example. Analysis of precipitation and water vapor datasets, and other observational data, would complement the reanalysis data we used, and would help in quantifying impacts in ways meaningful to operators. The use of sea state and ocean reanalysis datasets would extend this research to maritime operations.

We recommend that additional climate variations be explored for the HOA region. Our preliminary assessments of the MJO and NAO impacts on HOA precipitation variability indicated that the MJO is an especially promising candidate for future research. The recent research by Vorhees (2006) on MJO impacts on the northern IO and southwest Asia strongly supports this conclusion.

F. RECOMMENDATIONS TO DOD LEADERSHIP

As an initial step in modernizing military climatology products, we recommend that DoD leaders consider directing METOC personnel and operational users of DoD climatology services to collaborate to identify high priority areas for immediate smart climatology updates. This includes, but is not limited to identification of: key geographic regions; time scales; operations types; weapons systems; and environmental phenomena type. This prioritization will optimize the use of limited resources in the advancement of climatology work.

We recommend that AFW, AFCCC, and other DoD climate organizations consider specifically training and designating personnel to conduct advanced climatology work. This could be accomplished through distance learning, or perhaps video tele-conferencing with Naval Postgraduate School faculty. AFW master's and doctoral candidates with climate, forecasting, remote sensing, modeling, and general meteorology specializations can be specifically targeted for education and training in advanced climatology techniques, with follow-on assignments in this field. Several recent NPS graduates currently work at AFCCC, and have been trained in many aspects of the modern climatology processes that we have described and demonstrated in this study.

Finally, we recommend that AFW leadership consider directing and facilitating collaboration with civilian climate organizations in order to determine where deficiencies exist and leverage modern climatology work already being accomplished. The DoD

posts senior officer level METOC representatives at several civilian organizations such as NOAA and NCEP. Strategic partnerships between these organizations and AFCCC in the realm of advanced climate work will prove mutually beneficial, and optimize characterization of the battlespace for combatant commanders.

APPENDIX – FIGURES

Figure 1. The Horn of Africa. [After: Central Intelligence Agency (CIA), available online from http://www.lib.utexas.edu/maps/africa.html]. Accessed 20 March 2006.

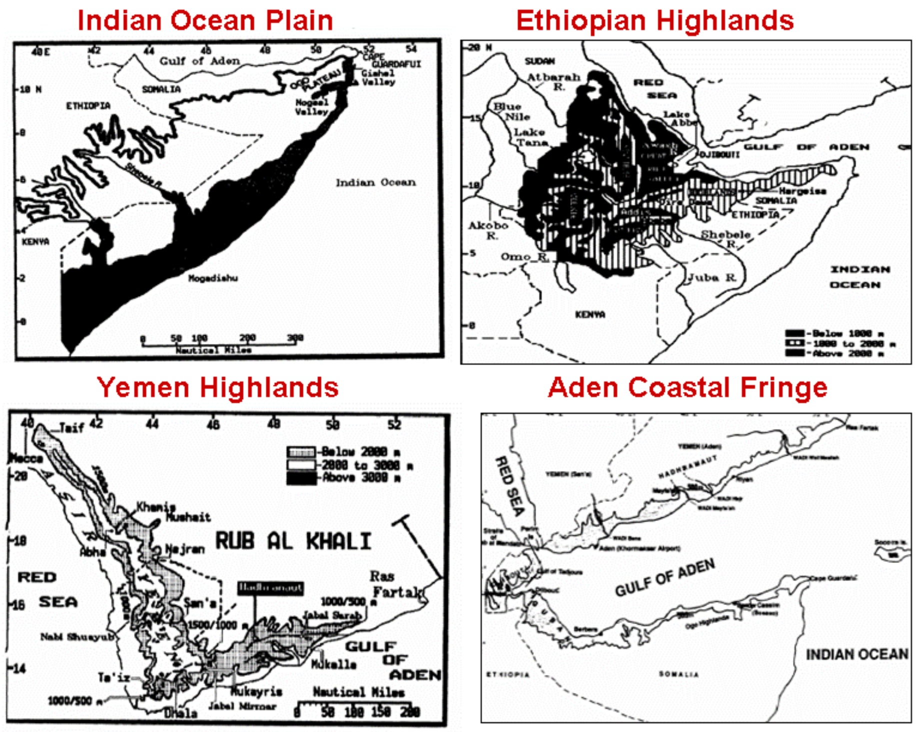

Figure 2. Climatically similar sub-regions of HOA. [After: Vojtesak et al. 1990].

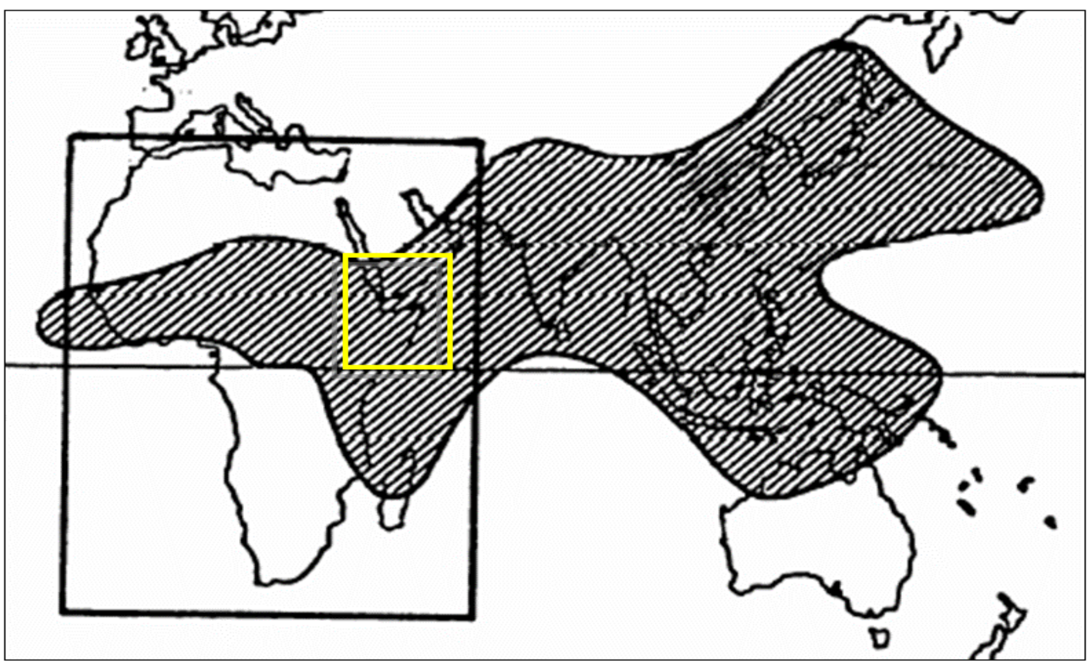

Figure 3. Monsoonal regions. Yellow box indicates the HOA. [After: Vojtesak et al. 1990].

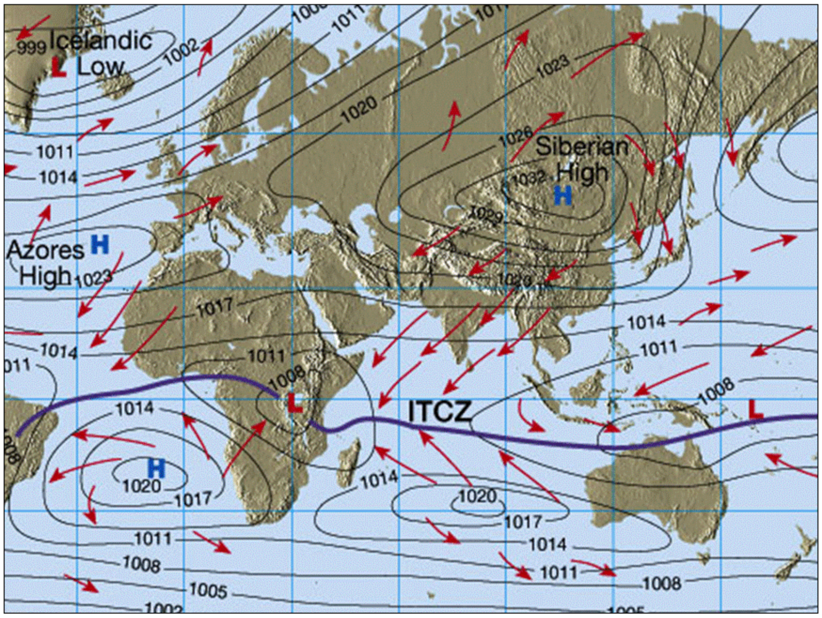

Figure 4. Schematic illustration of the major circulation features during the January peak of the Asian Winter Monsoon. [From: Lutgens and Tarbuck (2001), available online from http://www.ux1.eiu.edu/~cfjps/1400/circulation.html]. Accessed 20 March 2006.

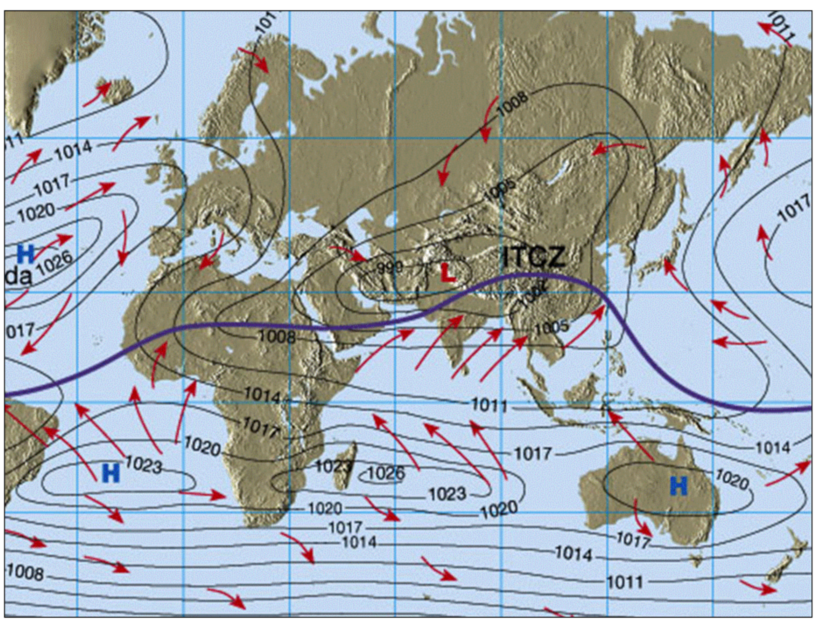

Figure 5. Schematic illustration of the major circulation features during the July peak of the Asian Summer Monsoon. [From: Lutgens and Tarbuck (2001), available online from http://www.ux1.eiu.edu/~cfjps/1400/circulation.html]. Accessed 20 March 2006.

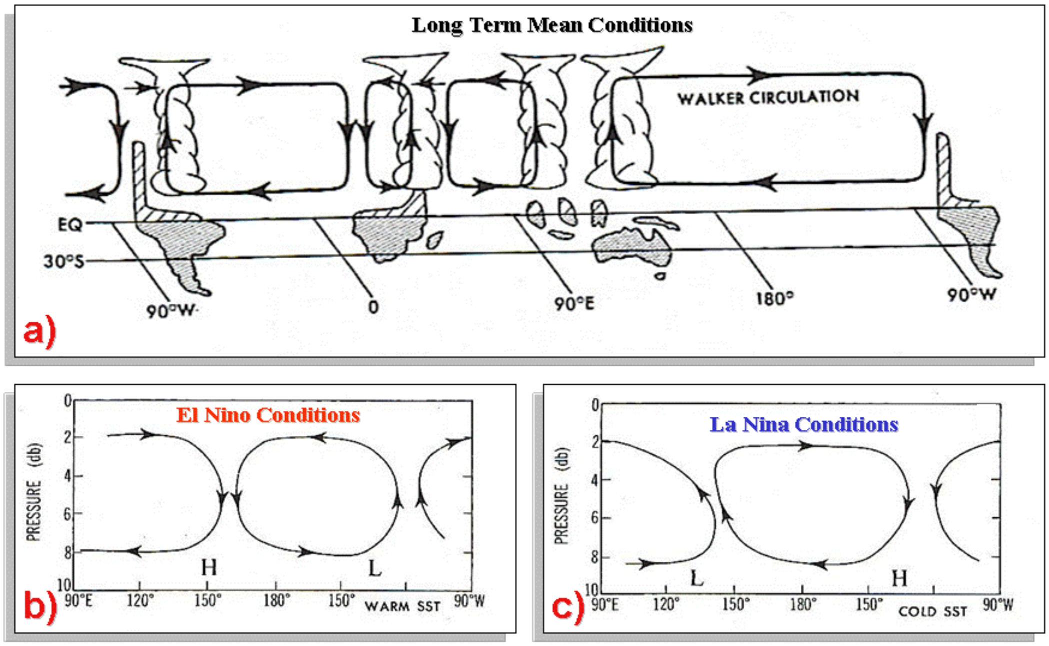

Figure 6. Schematic representation of the equatorial zonal component of the Hadley-Walker Circulation: a) long term mean zonal equatorial HWC, b) anomalous zonal equatorial HWC during EN, and c) anomalous zonal equatorial HWC during LN. [After: Peixoto and Oort (1992)].

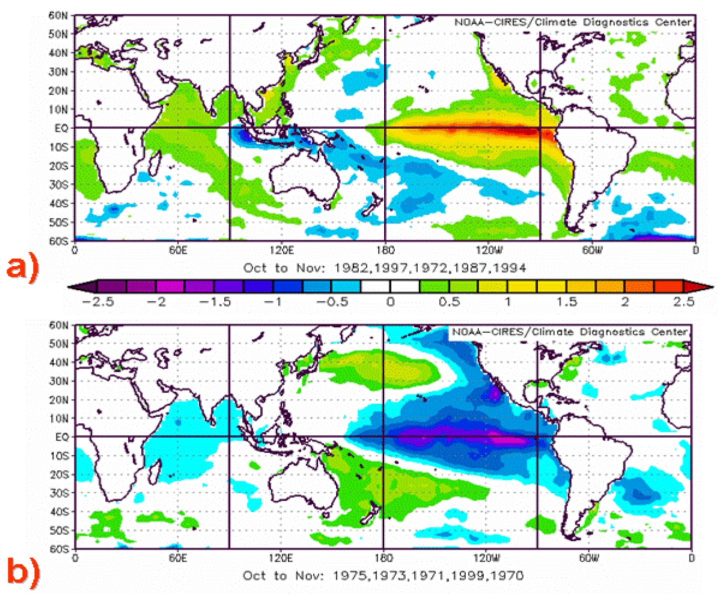

Figure 7. Sea surface temperature anomaly for October-November for: a) five strongest EN and b) five strongest LN events since 1960. Figures created using NCEP reanalysis data and CDC web site. [From: http://www.cdc.noaa.gov/cgi-bin/Composites/printpage.pl]. Accessed 20 March 2006.

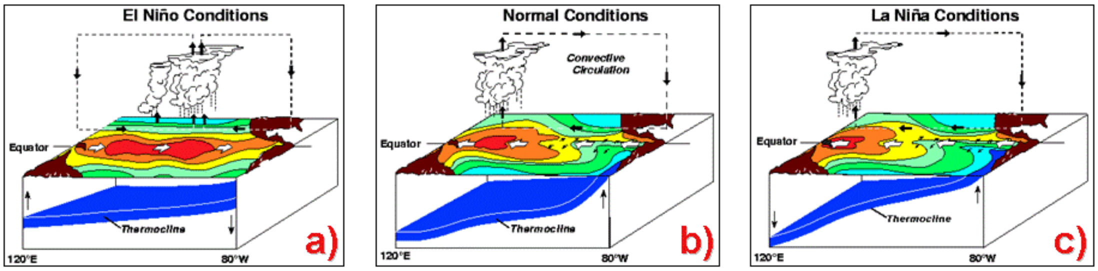

Figure 8. Schematic of tropical Pacific during a) El Nino, b) normal, and c) La Nina periods. [From: Pacific Marine Environmental Laboratory (PMEL), available online from http://www.pmel.noaa.gov/tao/elnino/nino-home.html#]. Accessed 20 March 2006.

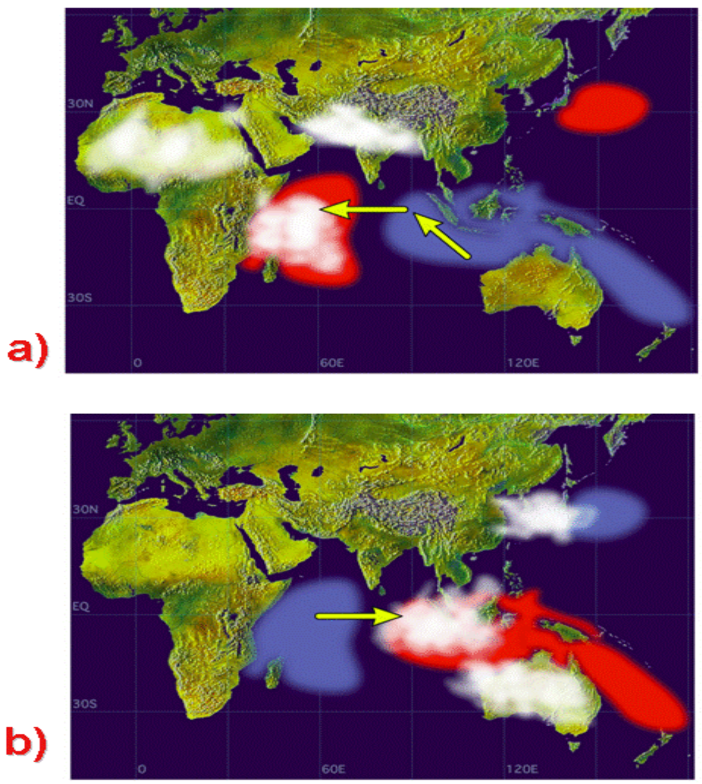

Figure 9. Schematic description of the main features of the Indian Ocean Zonal Mode (IOZM) during a) positive IOZM events and b) negative IOZM events. [From: Saji et al. (1999), available online from http://www.jamstec.go.jp/frsgc/research/d1/iod/]. Accessed 20 March 2006.

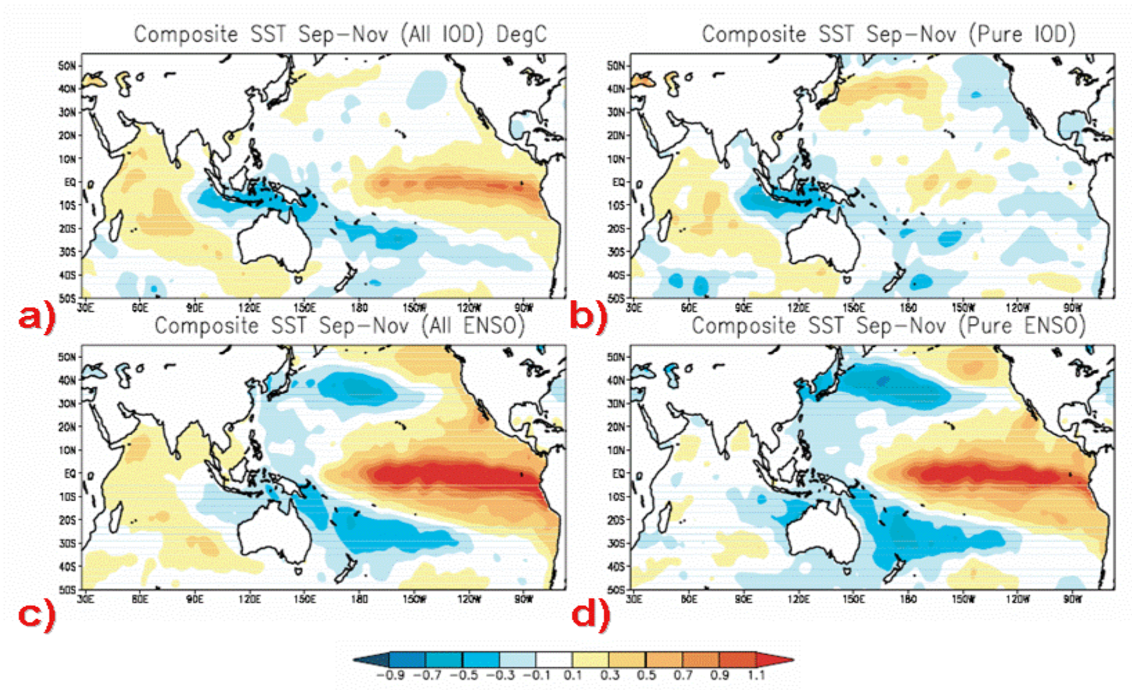

Figure 10. September-November composite SSTAs (°C) for a) all IOZM events, b) pure IOZM events, c) all EN events and, d) pure EN events. [From: Yamagata et al. (2002)].

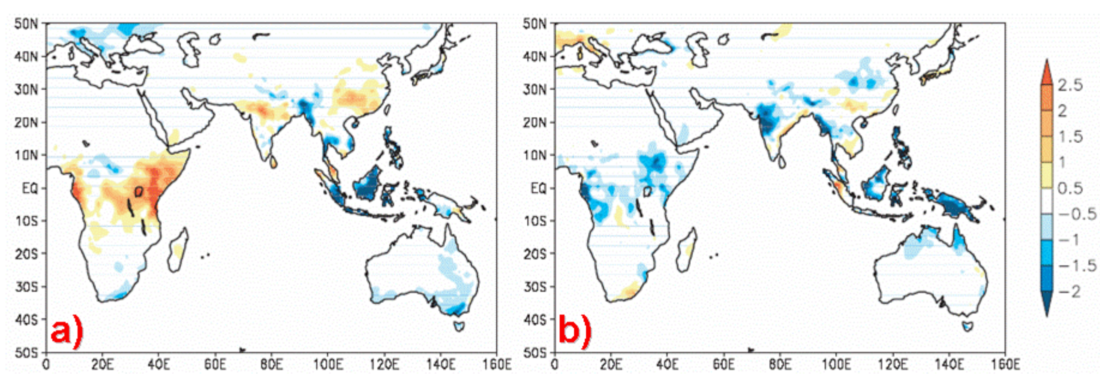

Figure 11. September-November composite rainfall anomalies (mm/day) for a) pure IOZM events and b) pure EN events. [From: Behera et al. (2004)].

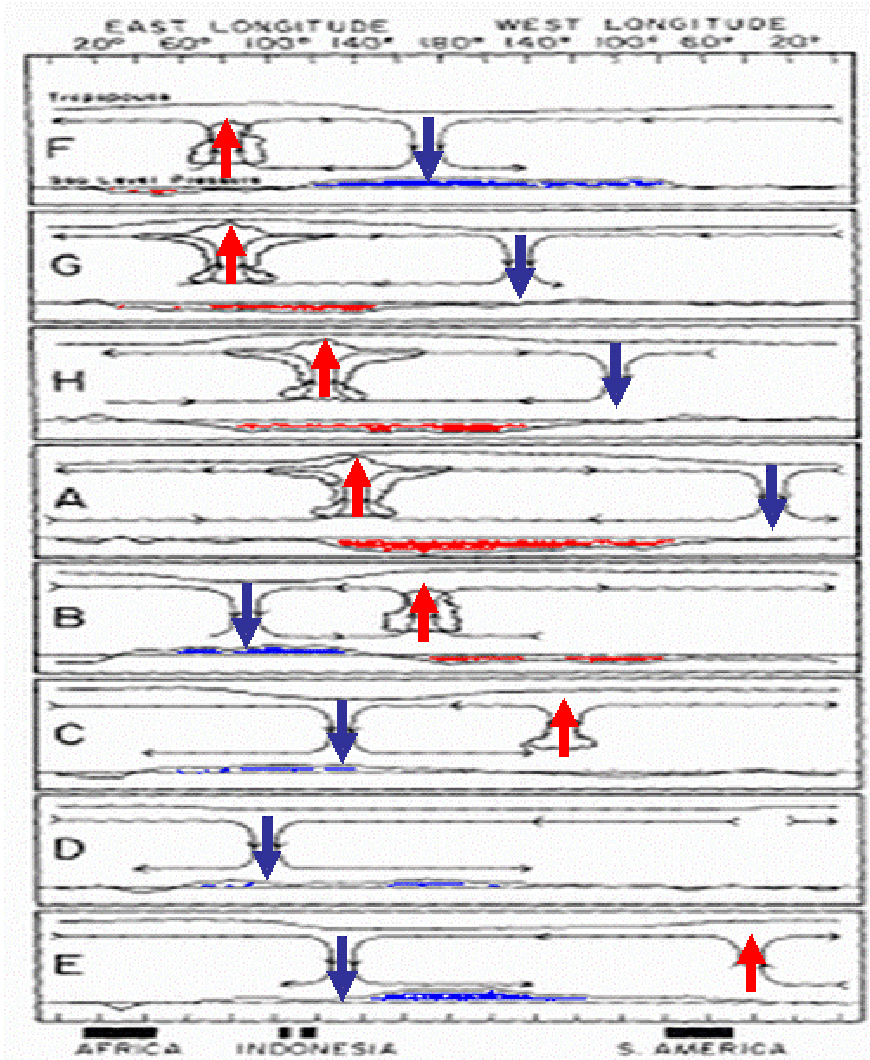

Figure 12. Schematic depiction of MJO vertical structure, propagation, and development as an MJO travels from the Indian Ocean into the Pacific. MJO convection tends to be most intense near the maritime continent, then weakens as it progresses eastward across the colder waters of the eastern Pacific. [After: Madden and Julian (1972)].

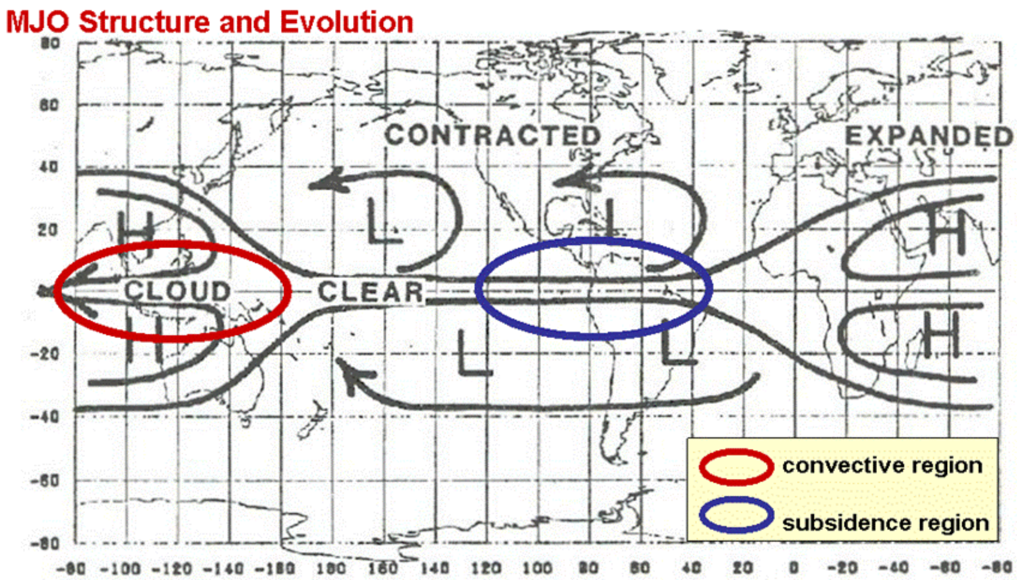

Figure 13. Schematic depiction of the upper tropospheric circulation anomalies associated with the MJO. [After: Wieckman et al. (1985)].

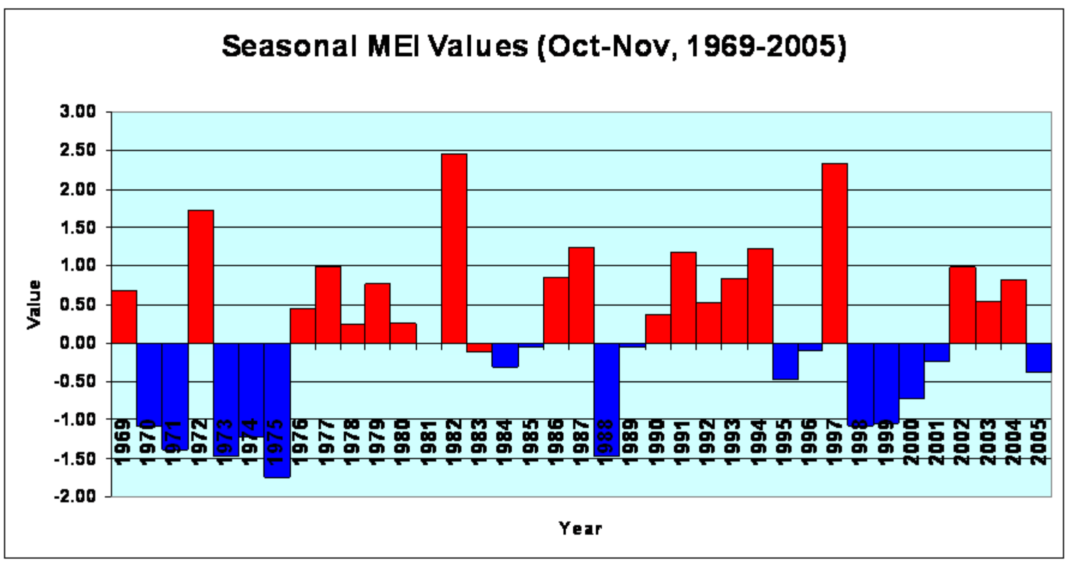

Figure 14. October-November values of the Multivariate ENSO Index (MEI), 1969-1999. Strong EN years are 1972, 1982, 1987, 1994, 1997. Strong LN years are 1971, 1973, 1974, 1975, 1988. [After: Wolter and Timlin (1993), data used in creating graph downloaded at Climate Diagnostics Center (CDC) world wide web site at http://www.cdc.noaa.gov/people/klaus.wolter/MEI/table.html]. Accessed 20 March 2006.

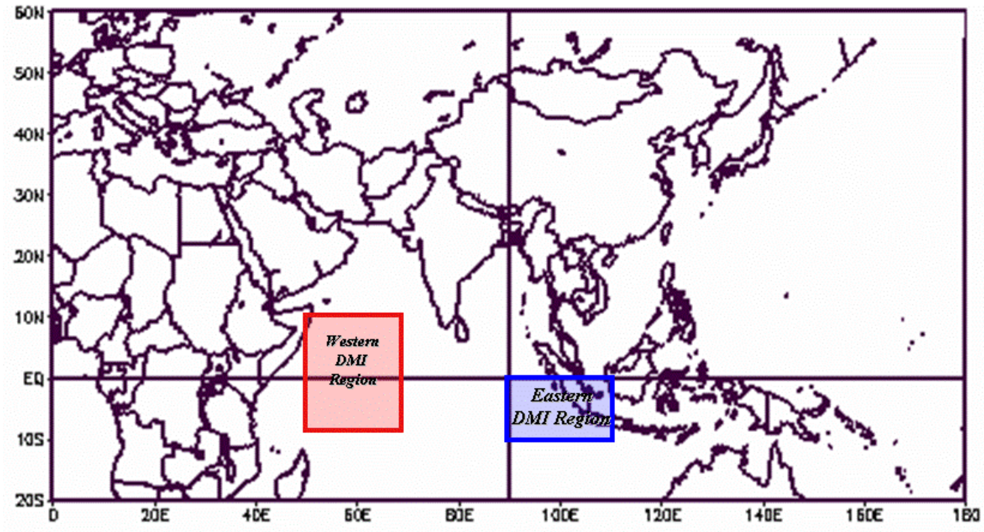

Figure 15. Red (blue) shaded box indicates western (eastern) region of the Indian Ocean monitored for SST anomalies used in the Indian Ocean Dipole Mode Index (DMI). [After: Saji et al. (1999)].

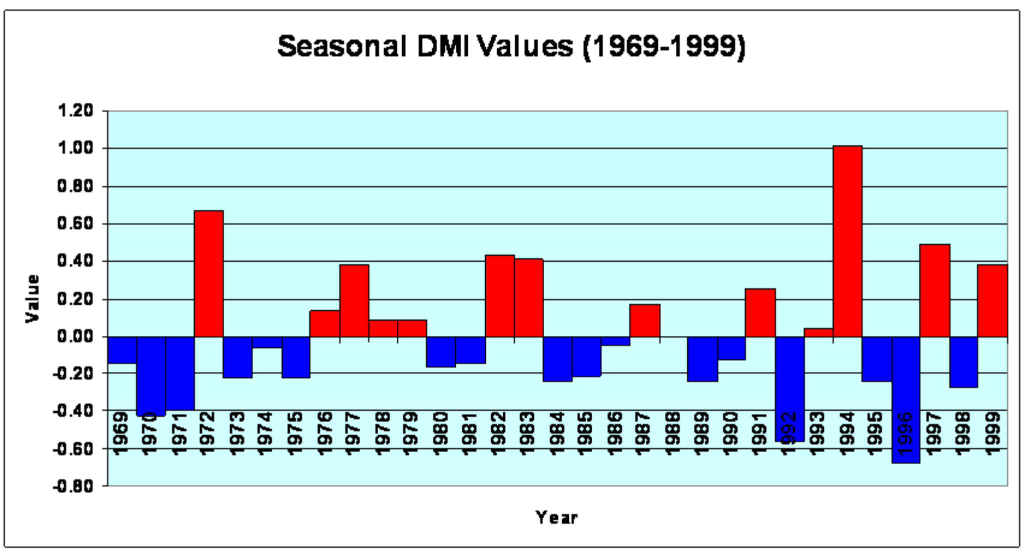

Figure 16. Seasonal values of the Dipole Mode Index (DMI), 1969-1999. Strong positive IOD events are 1972, 1982, 1983, 1994, and 1997. Strong negative IOD events are 1970, 1971, 1992, 1996, and 1998. [After: Rao et al. (2004)].

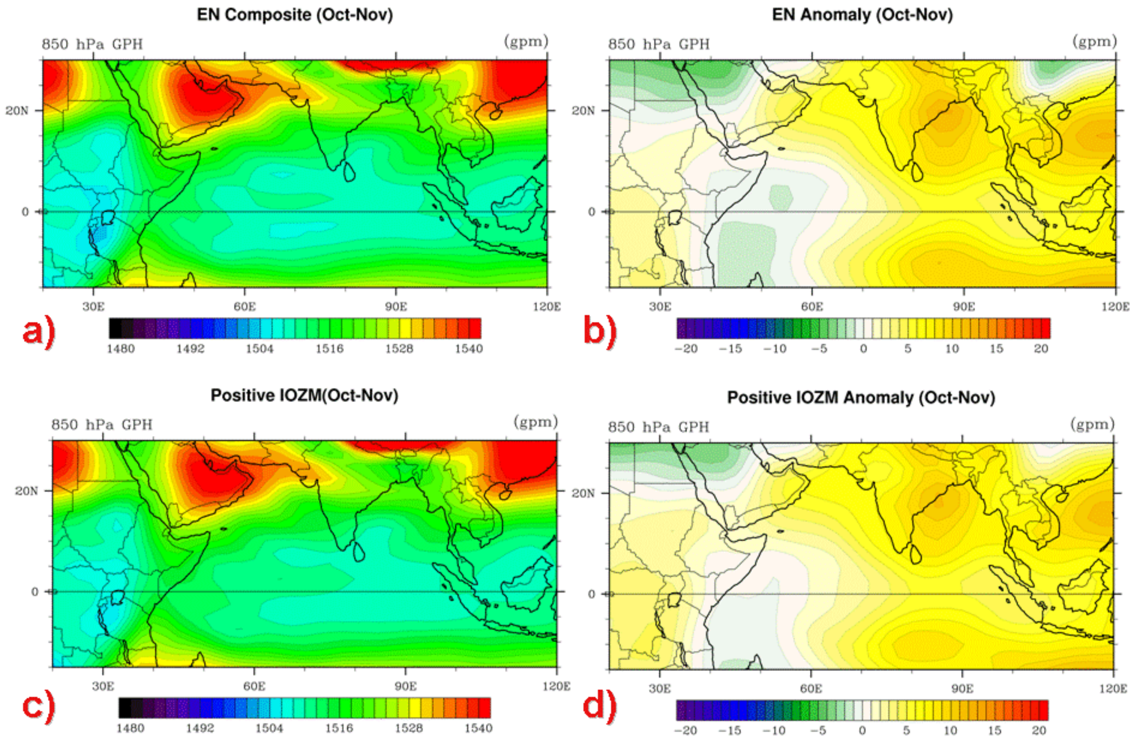

Figure 17. 850 hPa geopotential heights for: a) composite of five strongest EN events; b) composite anomaly of five strongest EN events; c) composite of five strongest positive IOZM events; and d) composite anomaly of five strongest positive IOZM events.

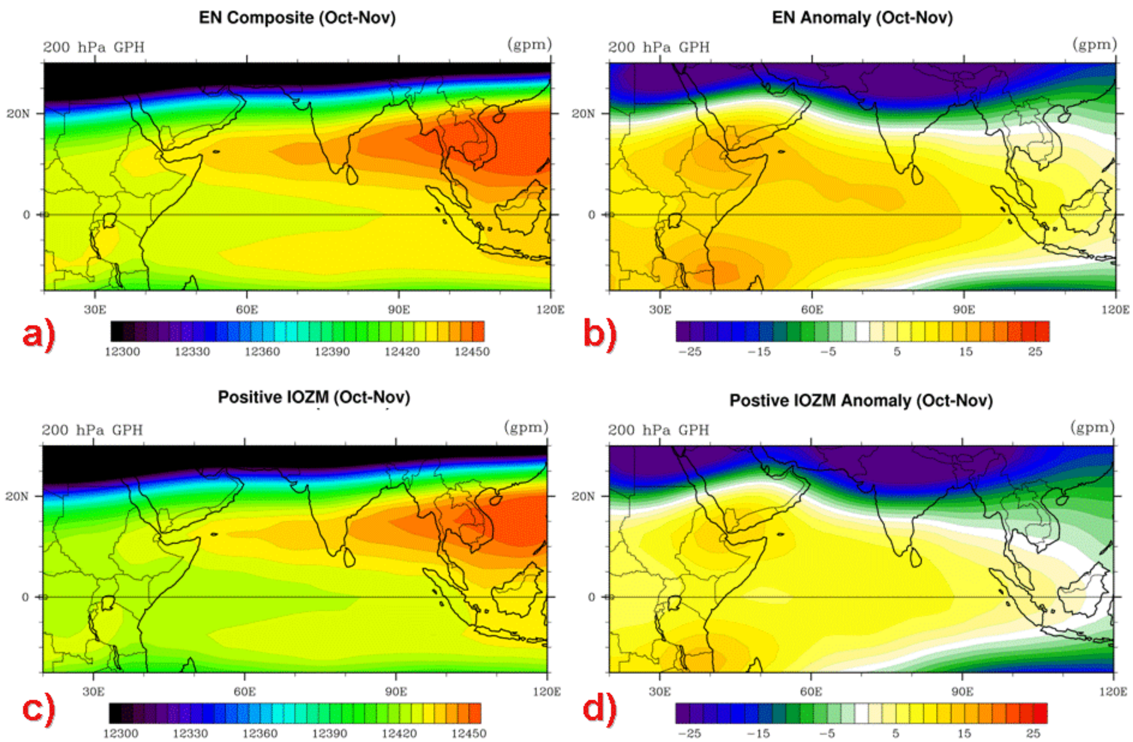

Figure 18. 200 hPa geopotential heights for: a) composite of five strongest EN events; b) composite anomaly of five strongest EN events; c) composite of five strongest positive IOZM events; and d) composite anomaly of five strongest positive IOZM events.

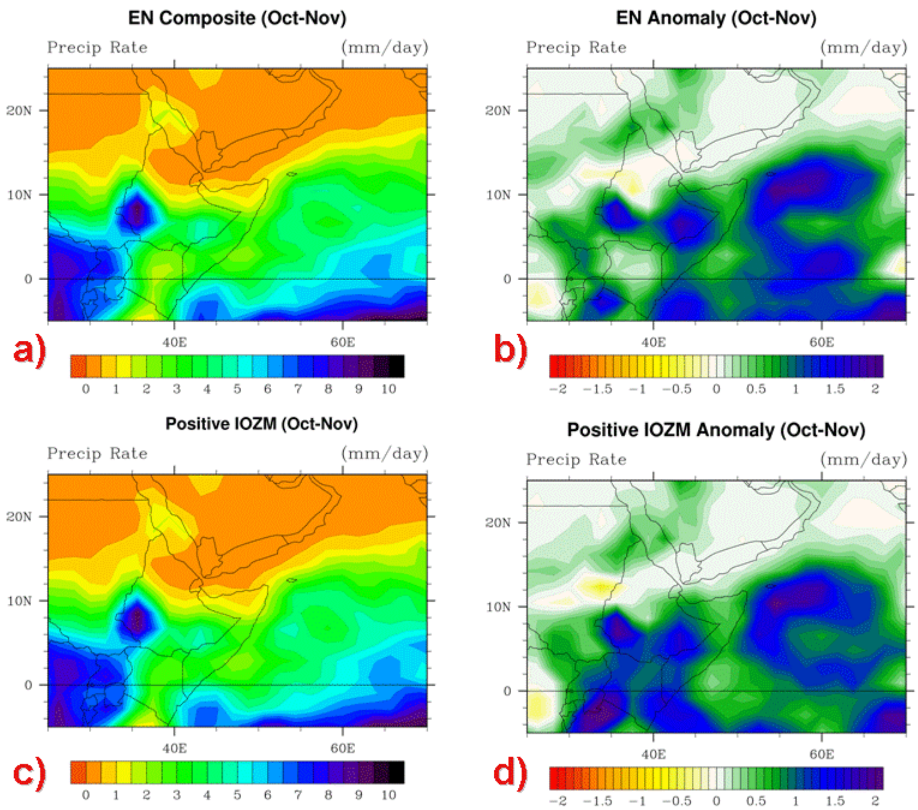

Figure 19. Precipitation rate for: a) composite of five strongest EN events; b) composite anomaly of five strongest EN events; c) composite of five strongest positive IOZM events; and d) composite anomaly of five strongest positive IOZM events.

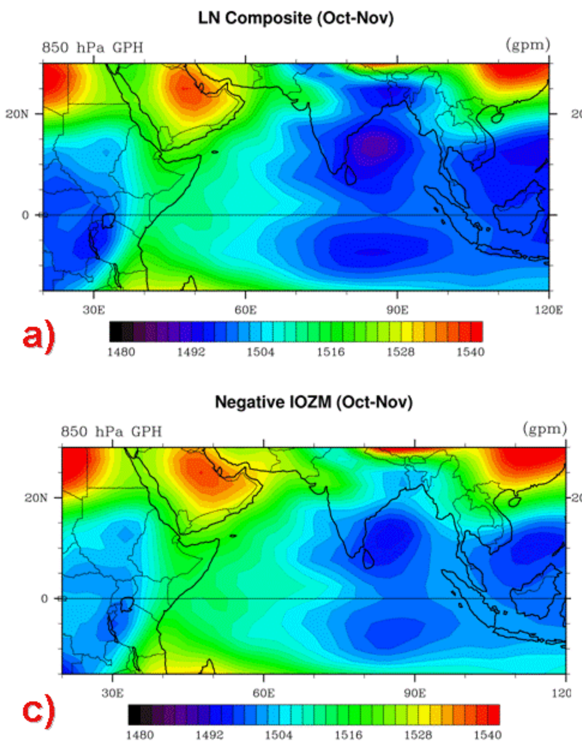

Figure 20. 850 hPa geopotential heights for: a) composite of five strongest LN events; b) composite anomaly of five strongest LN events; c) composite of five strongest negative IOZM events; and d) composite anomaly of five strongest negative IOZM events.

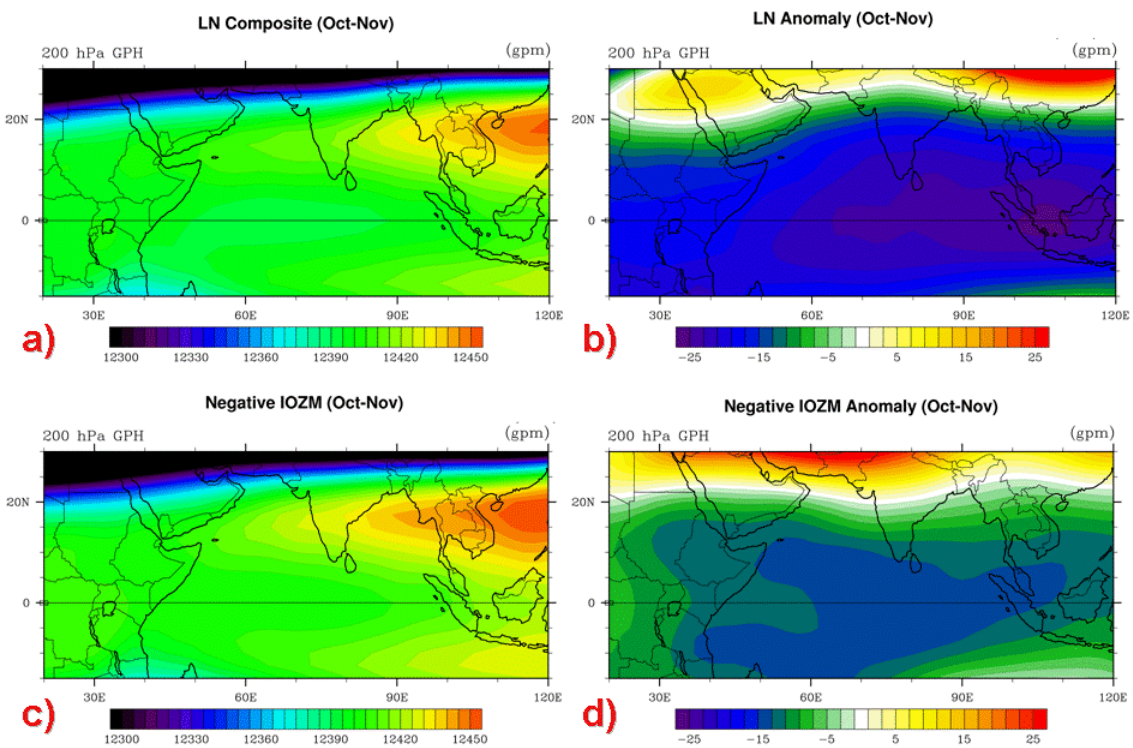

Figure 21. 200 hPa geopotential heights for: a) composite of five strongest LN events; b) composite anomaly of five strongest LN events; c) composite of five strongest negative IOZM events; and d) composite anomaly of five strongest negative IOZM events.

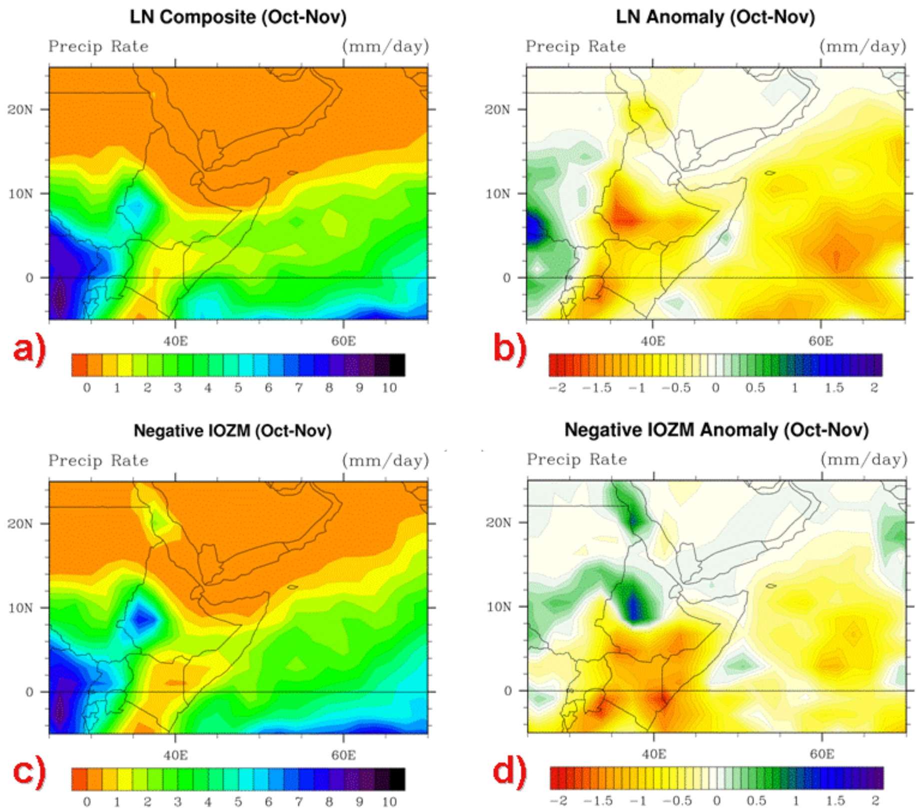

Figure 22. Precipitation rates for: a) composite of five strongest LN events; b) composite anomaly of five strongest LN events; c) composite of five strongest negative IOZM events; and d) composite anomaly of five strongest negative IOZM events.

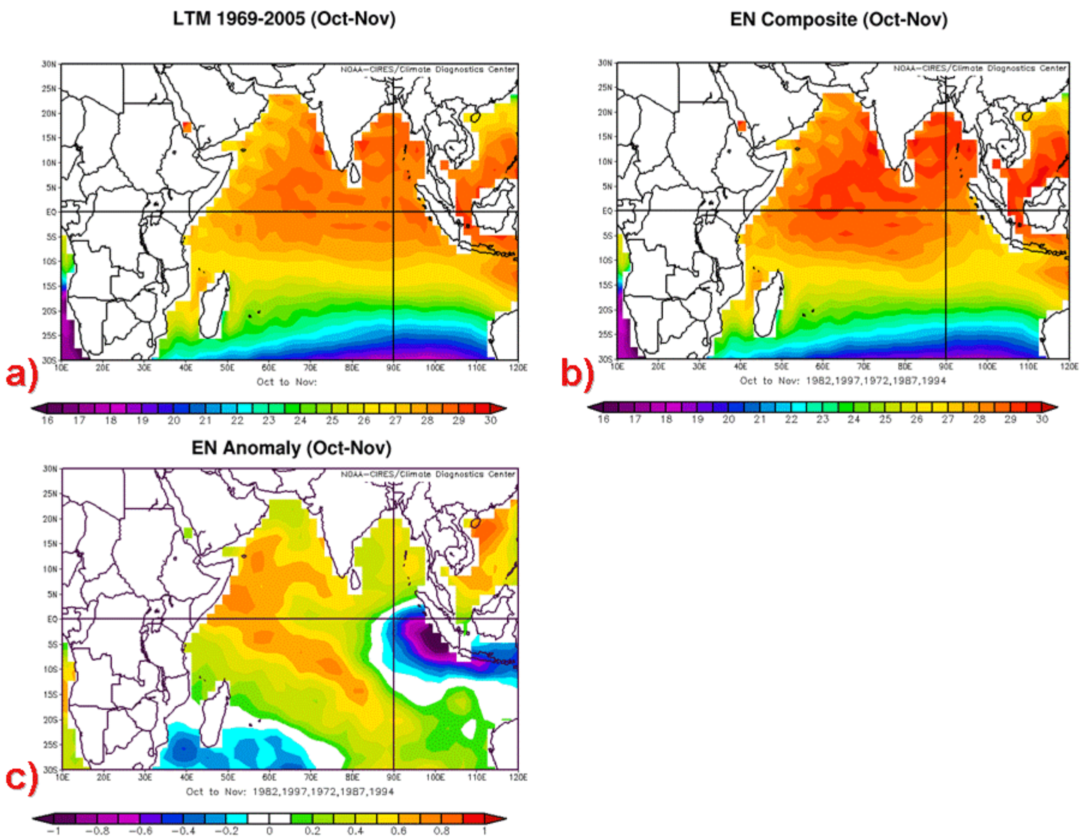

Figure 23. Sea surface temperatures (^{o}C) for: a) LTM; b) composite of five strongest EN events; c) composite anomaly of five strongest EN events.

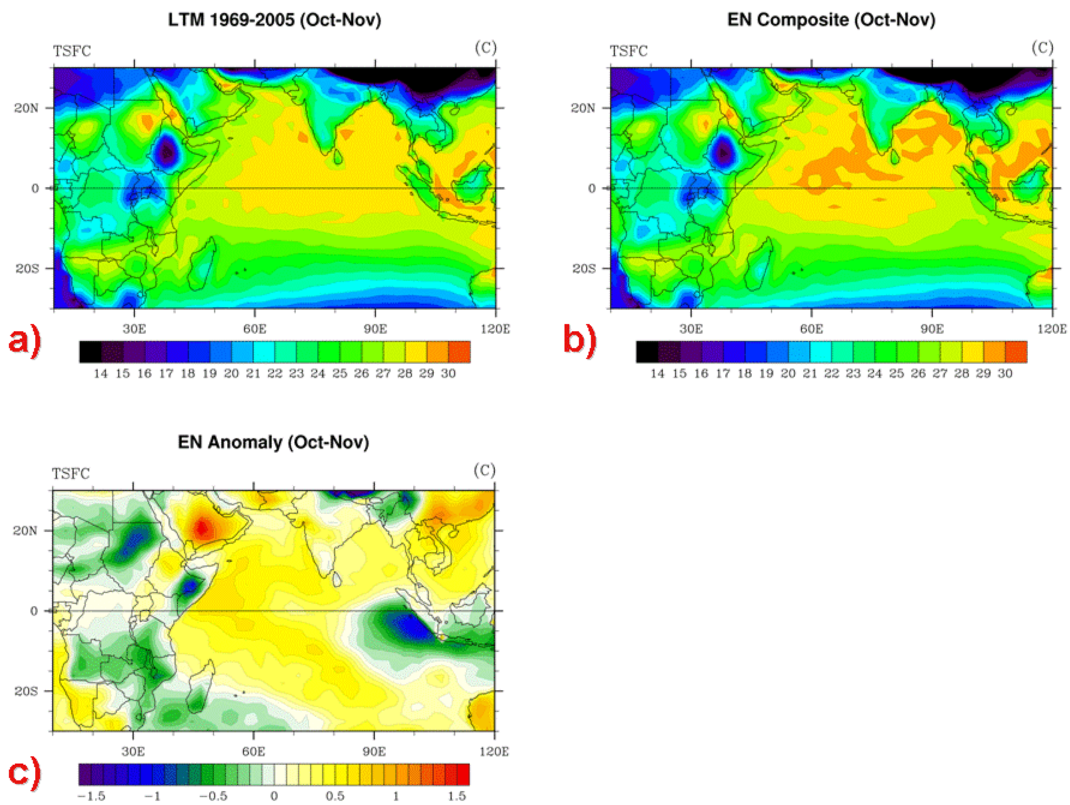

Figure 24. Surface air temperature for: a) LTM; b) composite of five strongest EN events; c) composite anomaly of five strongest EN events. Anomalous surface air temperature pattern closely resembles anomalous SST pattern, suggesting that SST anomalies may be driving the air temperature anomalies

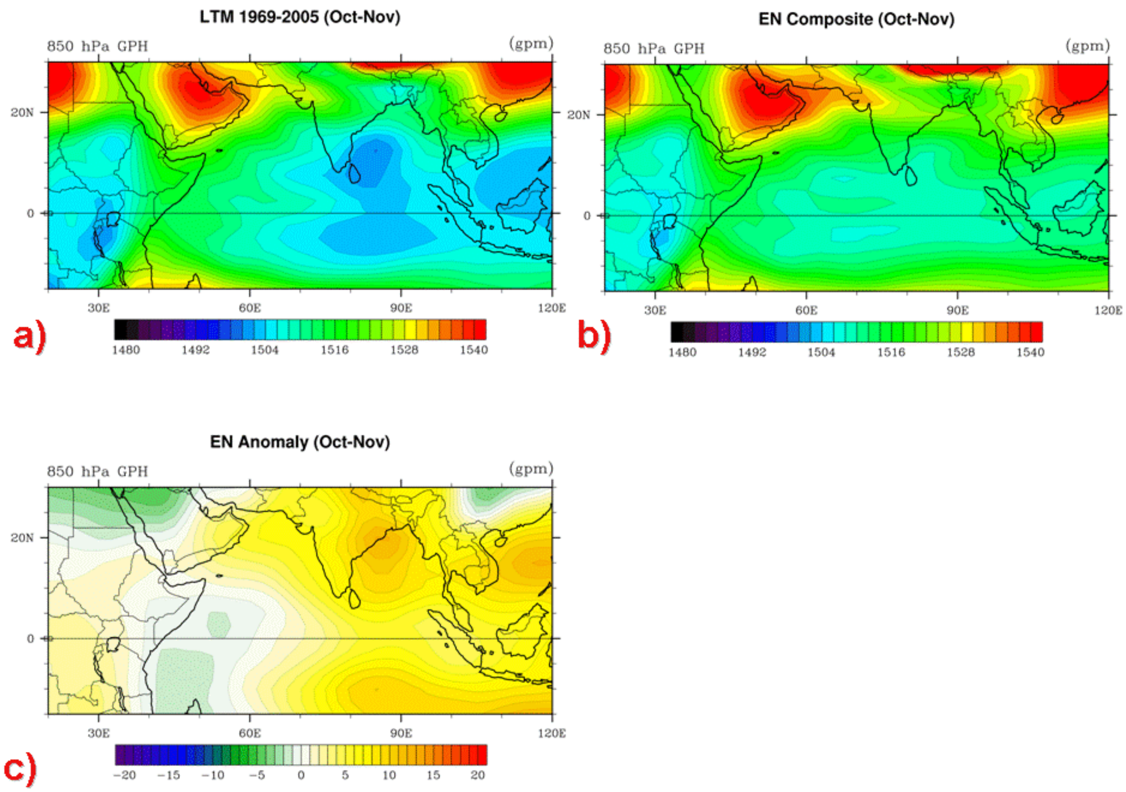

Figure 25. 850 hPa geopotential heights for: a) LTM; b) composite of five strongest EN events; c) composite anomaly of five strongest EN events.

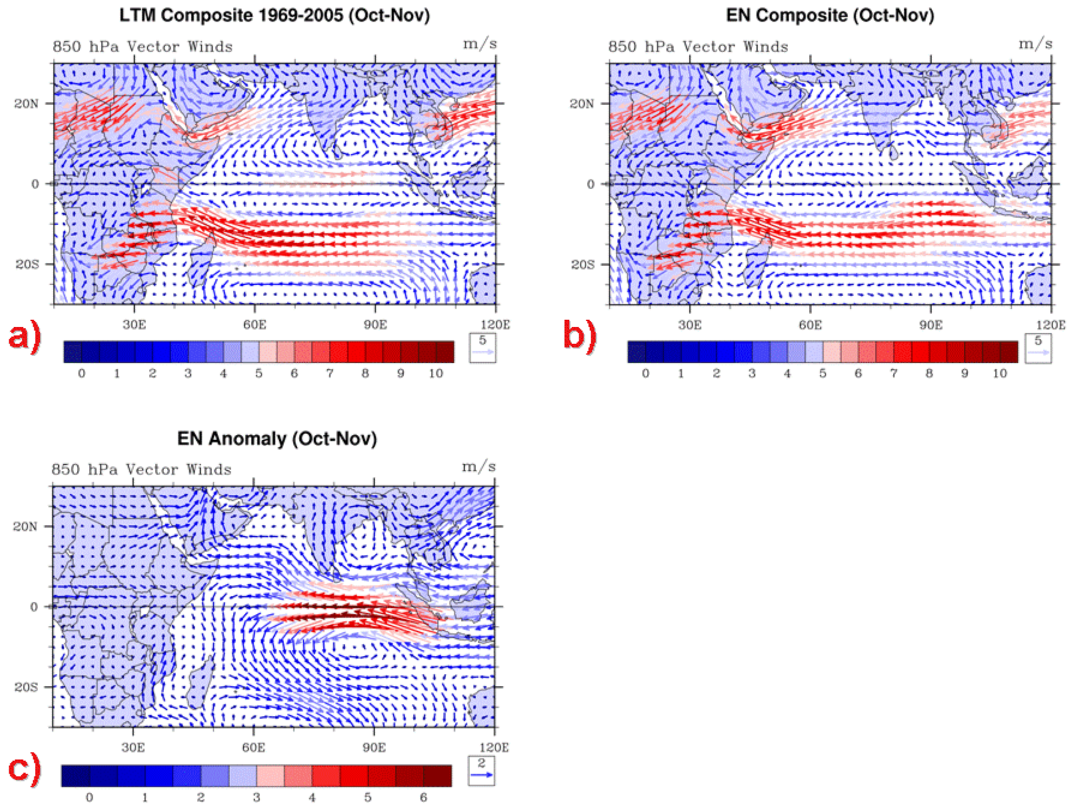

Figure 26. 850 hPa vector winds for: a) LTM; b) composite of five strongest EN events; c) composite anomaly of five strongest EN events.

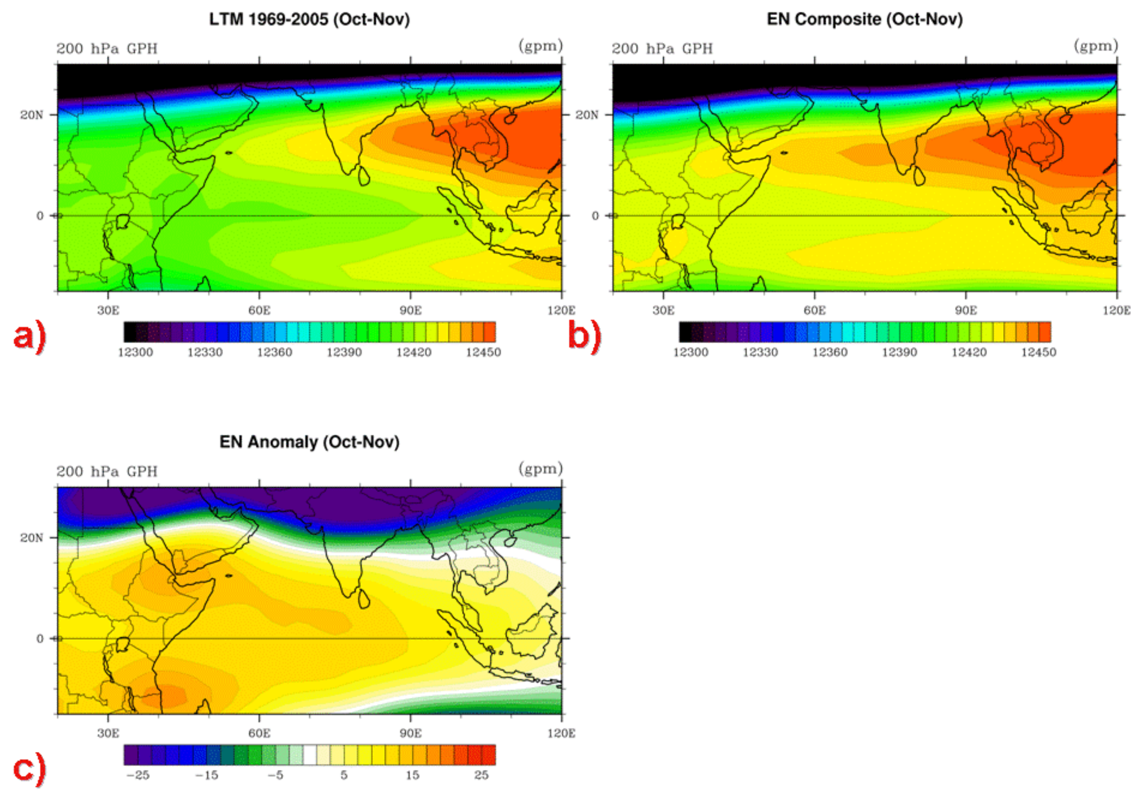

Figure 27. 200 hPa geopotential heights for: a) LTM; b) composite of five strongest EN events; c) composite anomaly of five strongest EN events

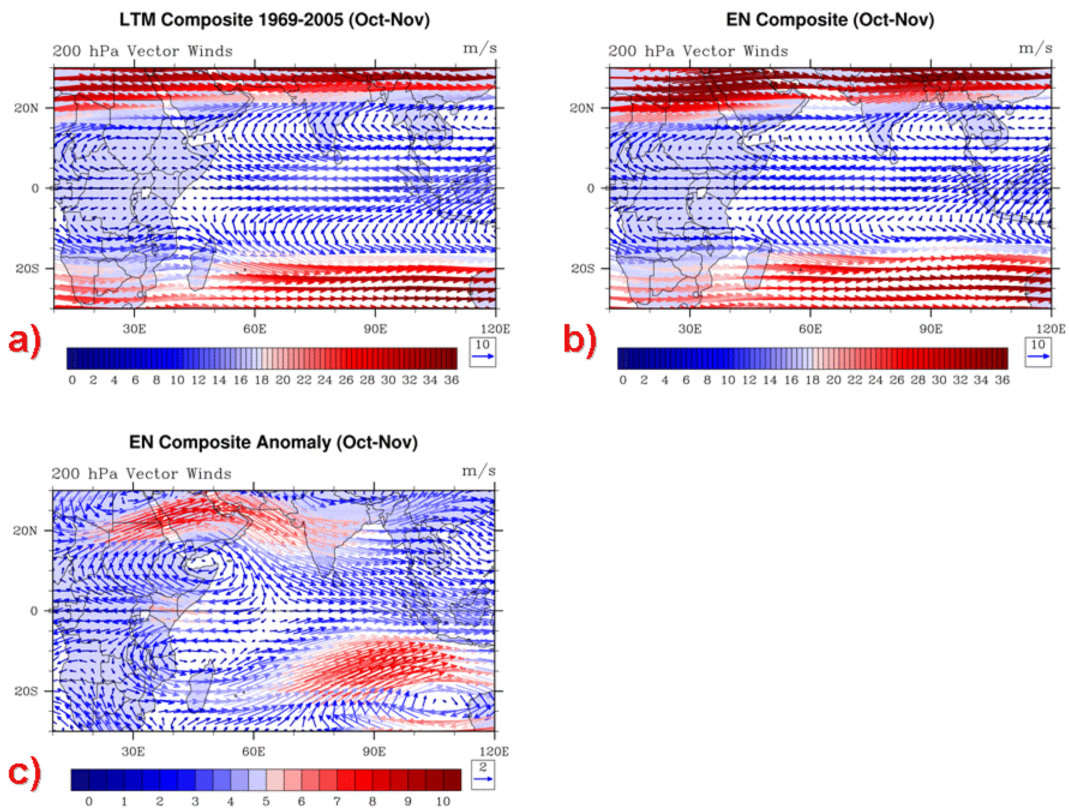

Figure 28. 200 hPa vector winds for: a) LTM; b) composite of five strongest EN events; c) composite anomaly of five strongest EN events.

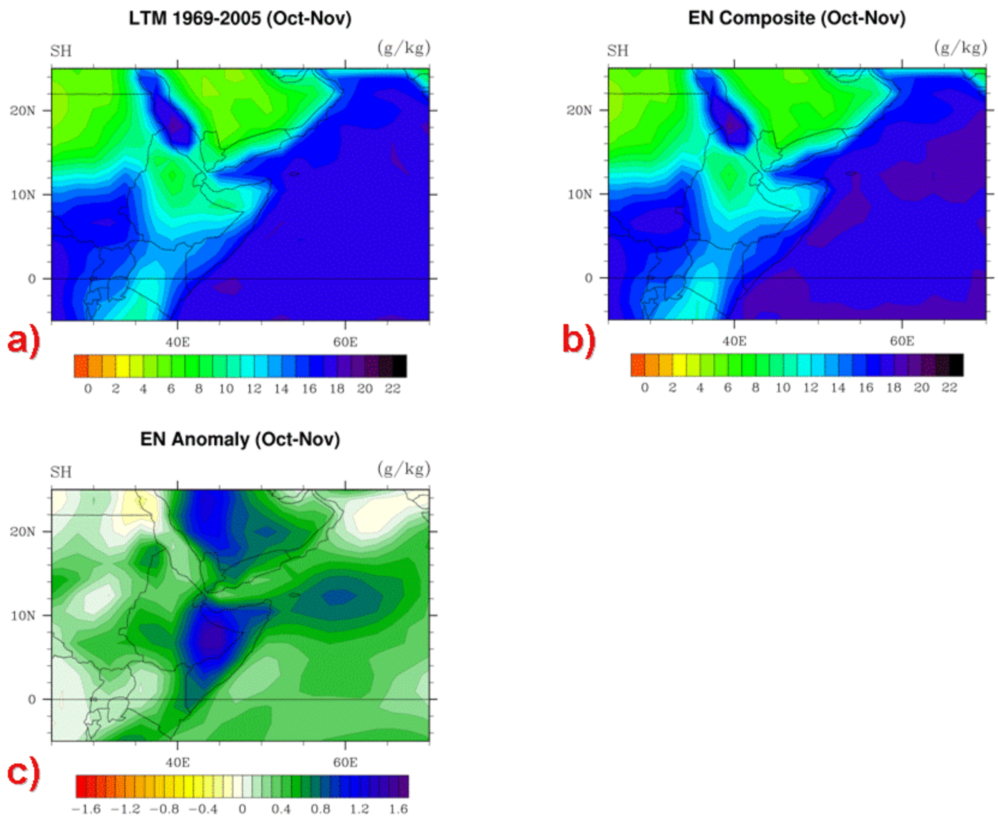

Figure 29. 850 hPa SH for: a) LTM; b) composite of five strongest EN events; c) composite anomaly of five strongest EN events.

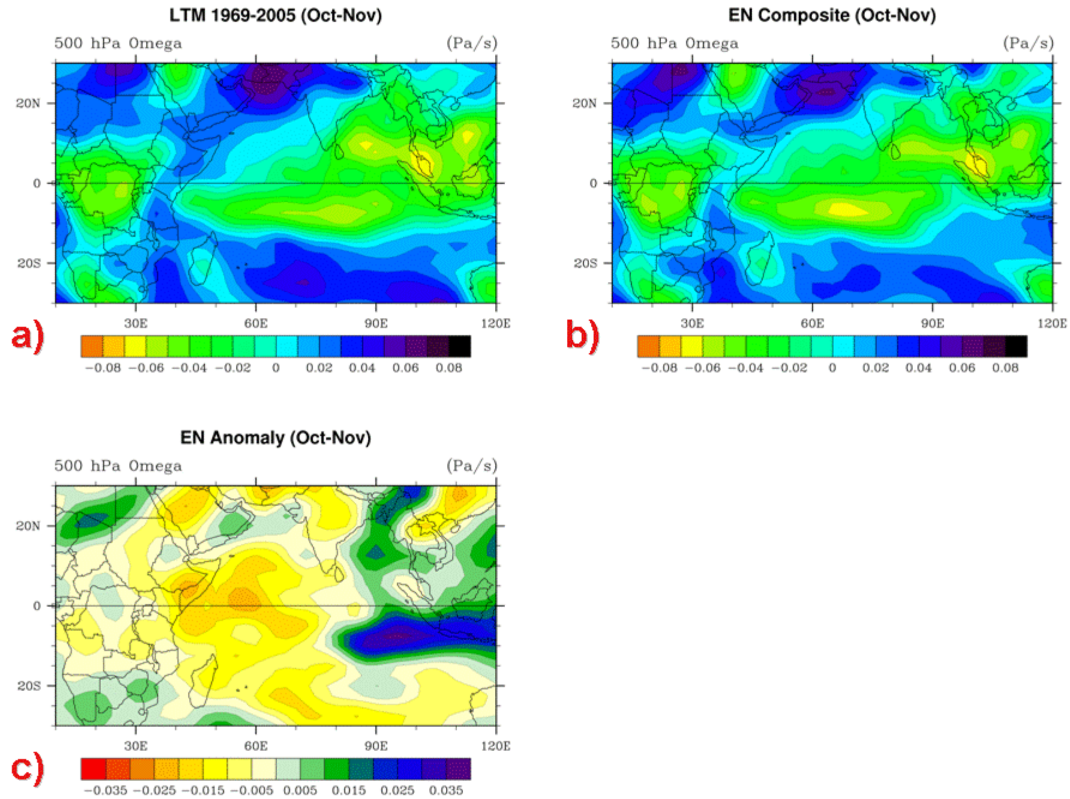

Figure 30. 500 hPa omega for: a) LTM; b) composite of five strongest EN events; c) composite anomaly of five strongest EN events.

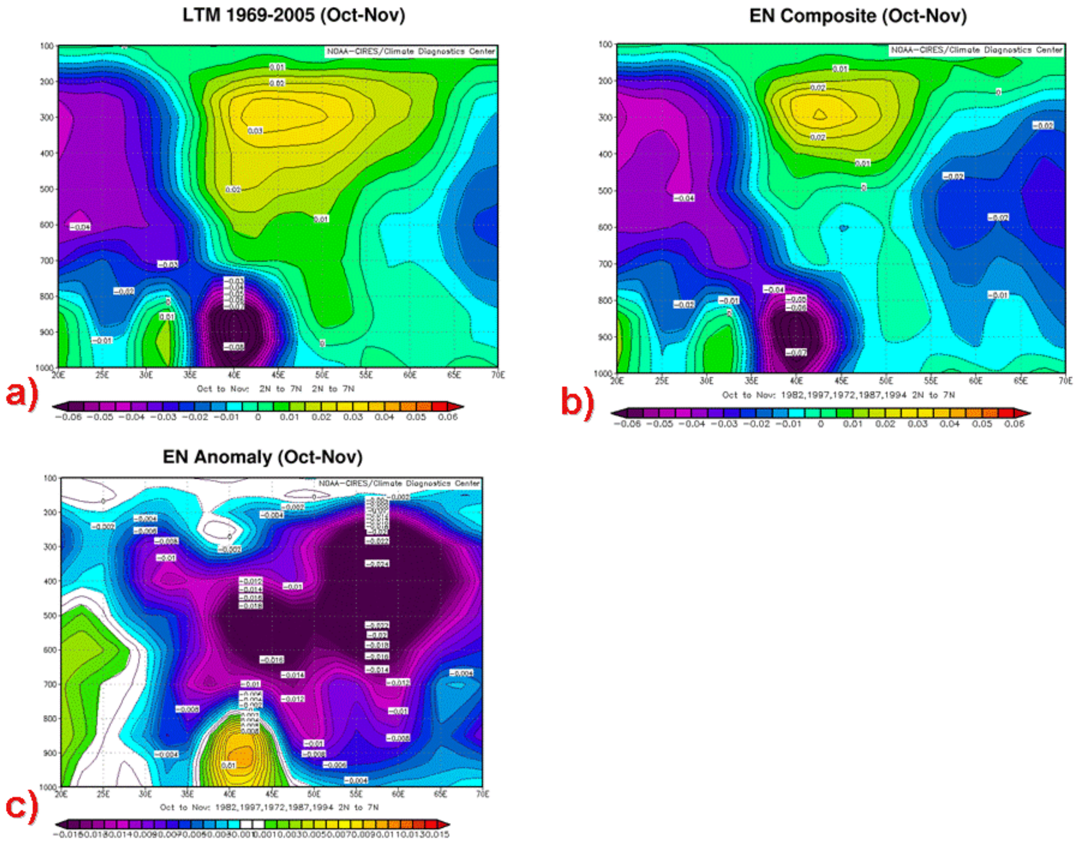

Figure 31. Omega vertical cross section averaged from 2°N to 7°N for: a) LTM; b) composite of five strongest EN events; c) composite anomaly of five strongest EN events.

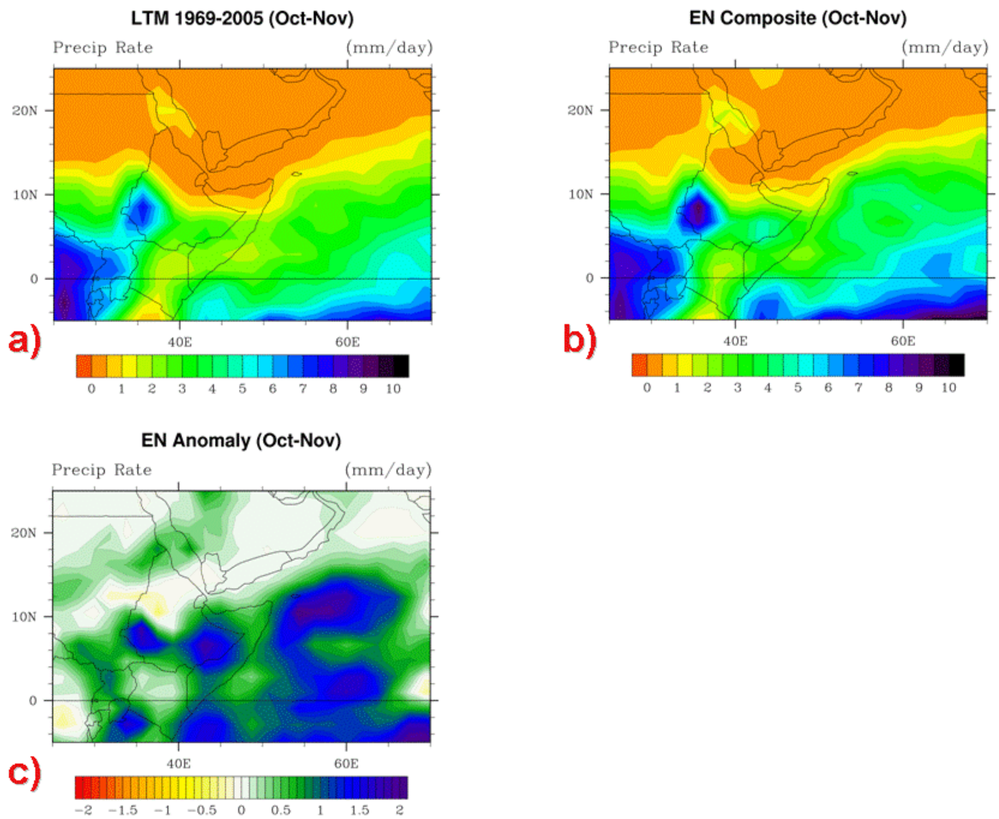

Figure 32. Surface precipitation rate for: a) LTM; b) composite of five strongest EN events; c) composite anomaly of five strongest EN events.

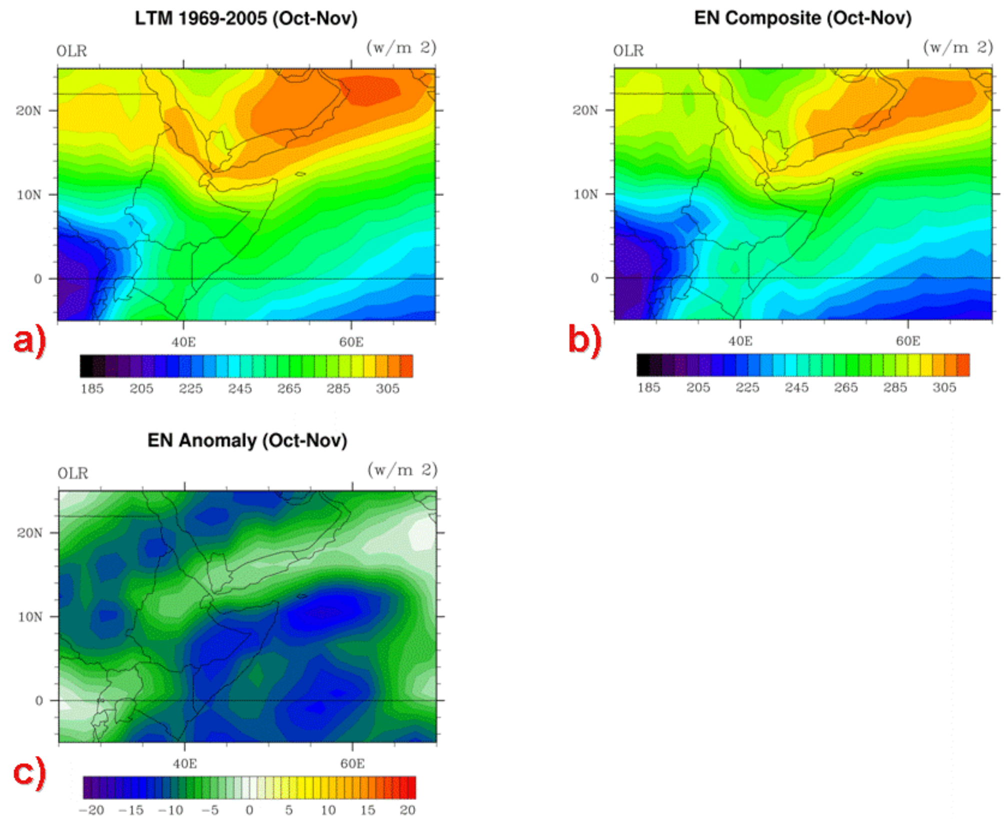

Figure 33. OLR for: a) LTM; b) composite of five strongest EN events; c) composite anomaly of five strongest EN events.

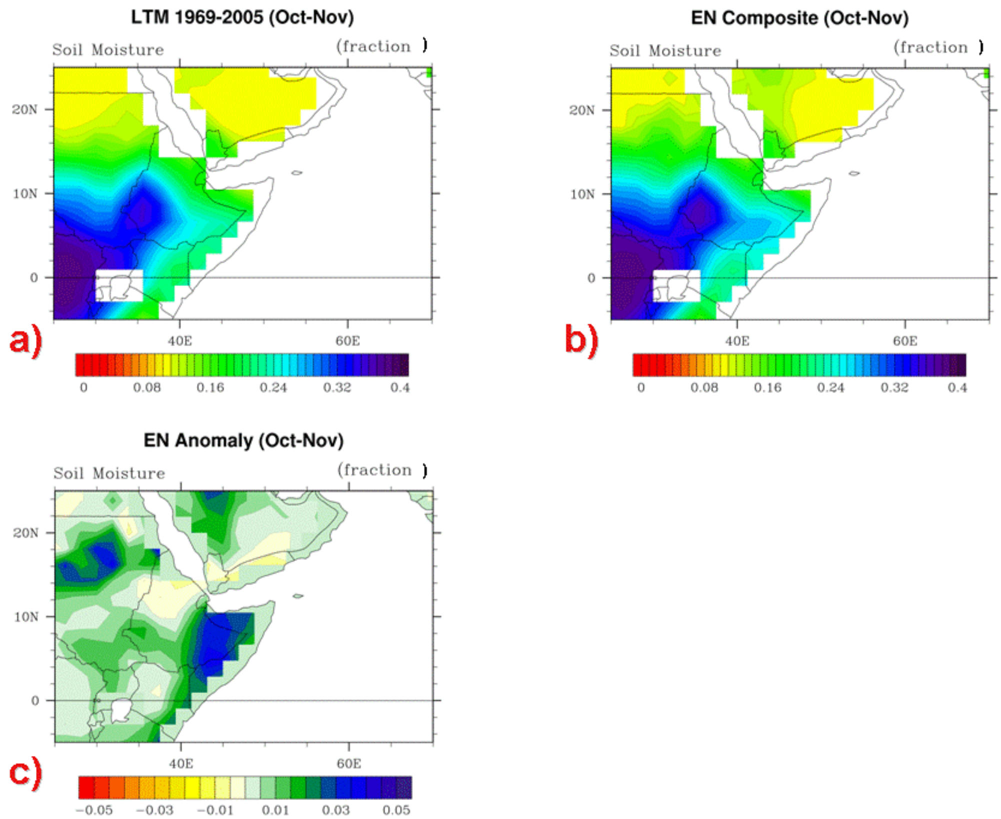

Figure 34. Volumetric soil moisture from the surface to a depth of 10 cm. for : a) LTM; b) composite of five strongest EN events; c) composite anomaly of five strongest EN events. Volumetric soil moisture is the percent water content per unit volume of soil.

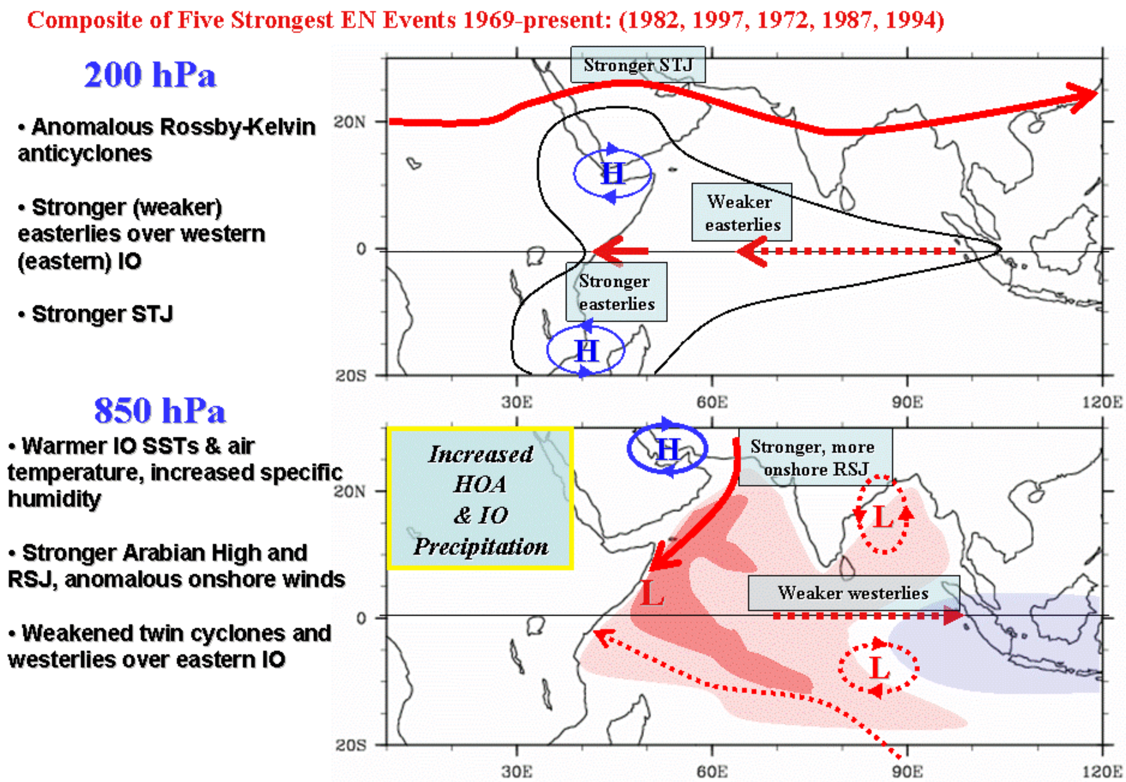

Figure 35. Schematic representation of anomalies associated with strong EN events at a) 200 hPa and b) 850 hPa. STJ = subtropical jet. RSJ = reverse Somali jet. IO = Indian Ocean.

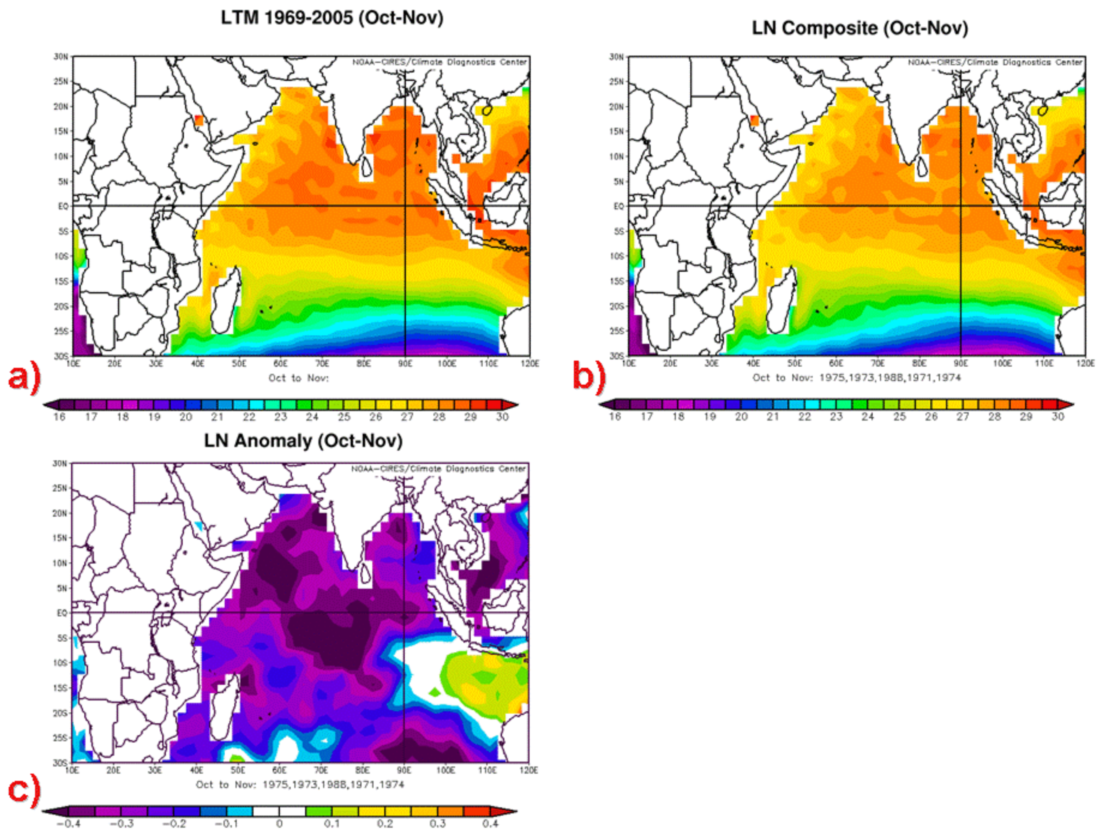

Figure 36. Sea surface temperatures (°C) for: a) LTM; b) composite of five strongest LN events; c) composite anomaly of five strongest LN events.

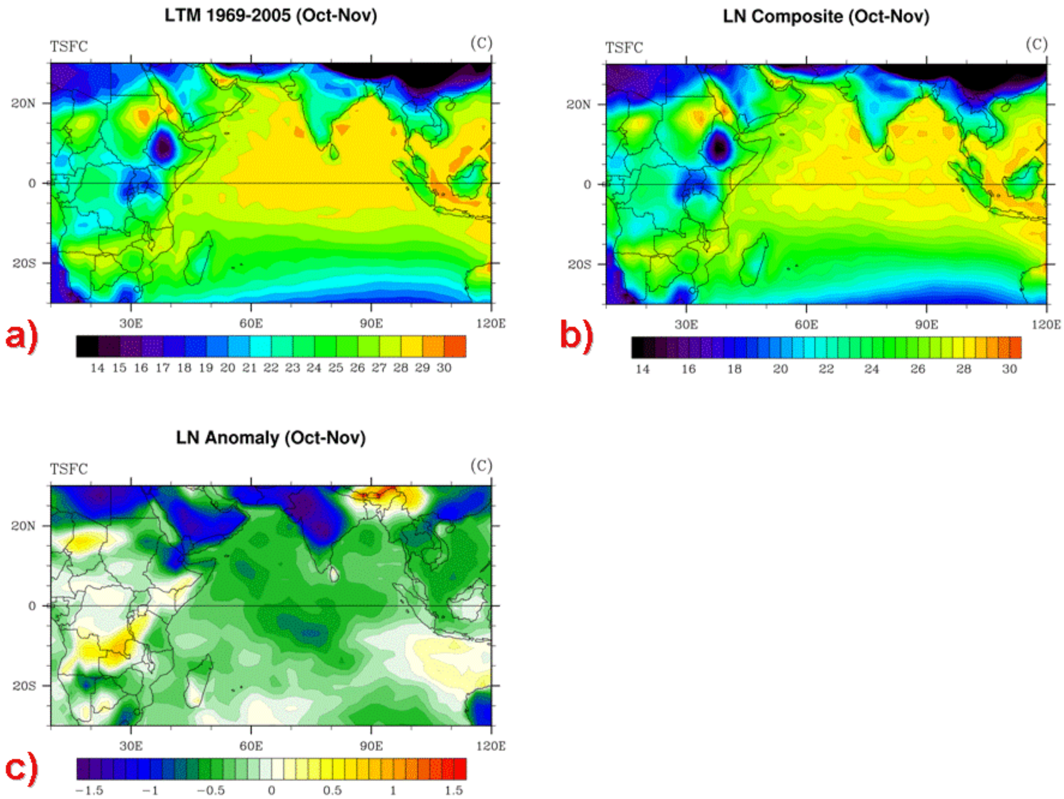

Figure 37. Surface air temperatures for: a) LTM: b) composite of five strongest LN events; c) composite anomaly of five strongest LN events.

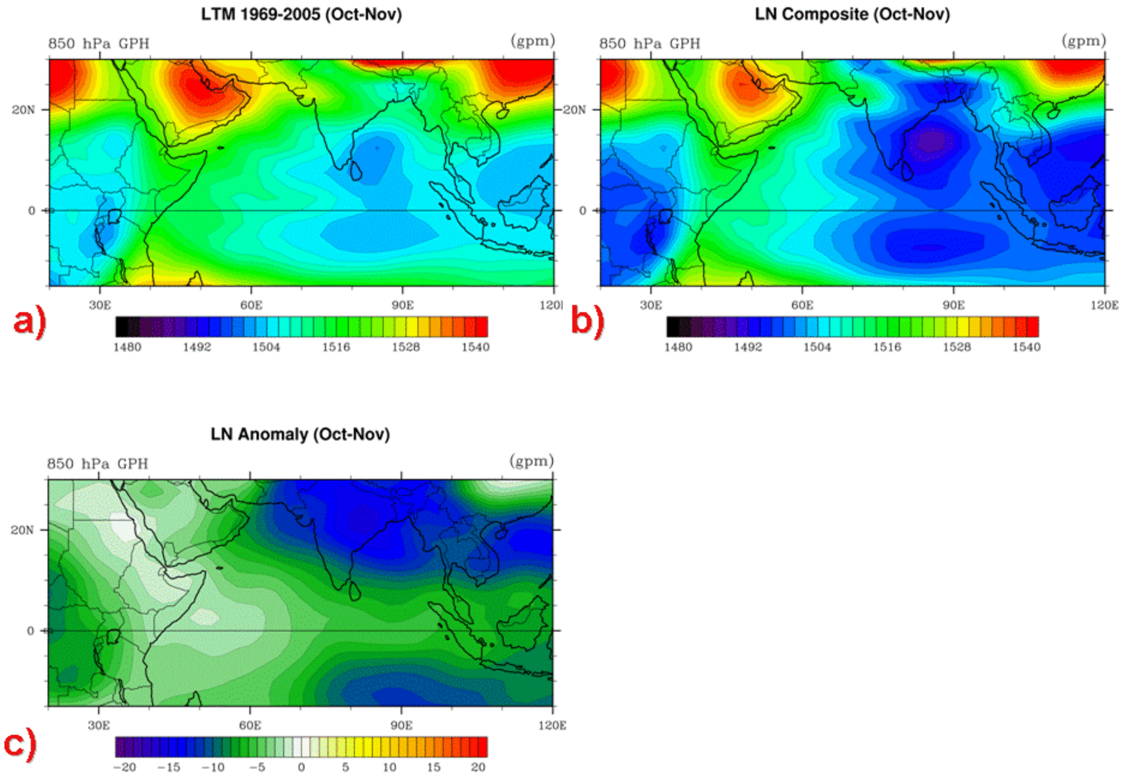

Figure 38. 850 hPa geopotential heights for: a) LTM; b) composite of five strongest LN events; c) composite anomaly of five strongest LN events.

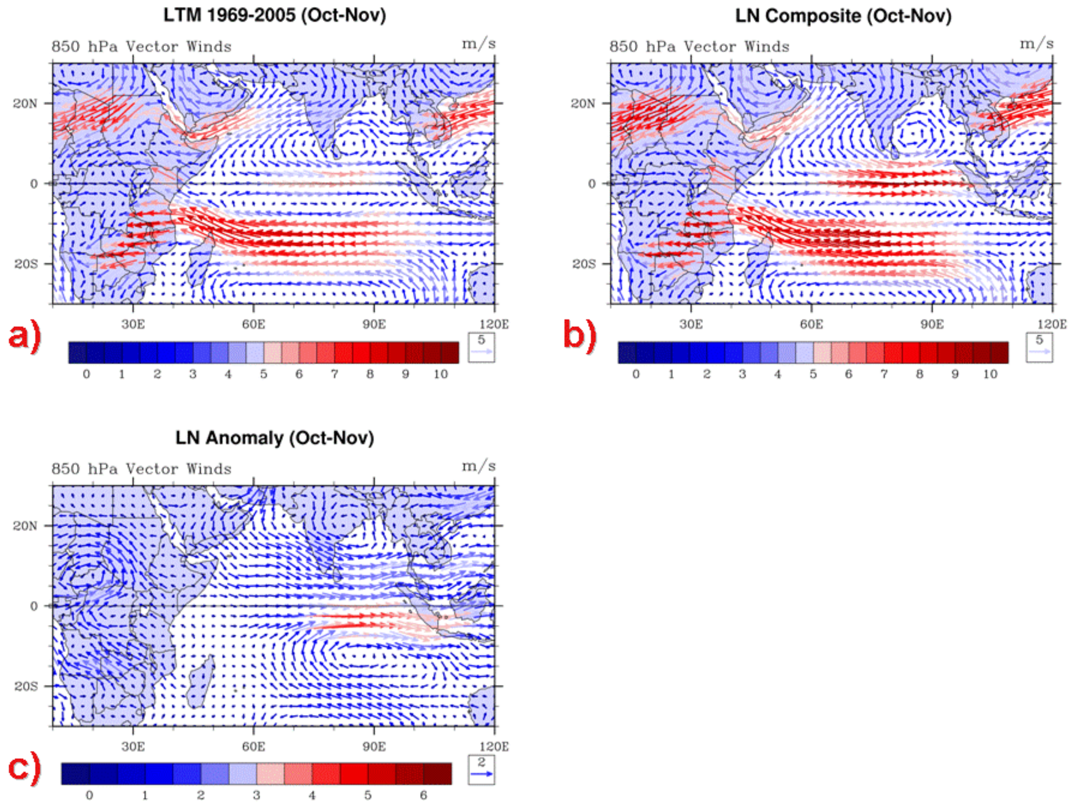

Figure 39. 850 hPa vector winds for: a) LTM; b) composite of five strongest LN events; c) composite anomaly of five strongest LN events.

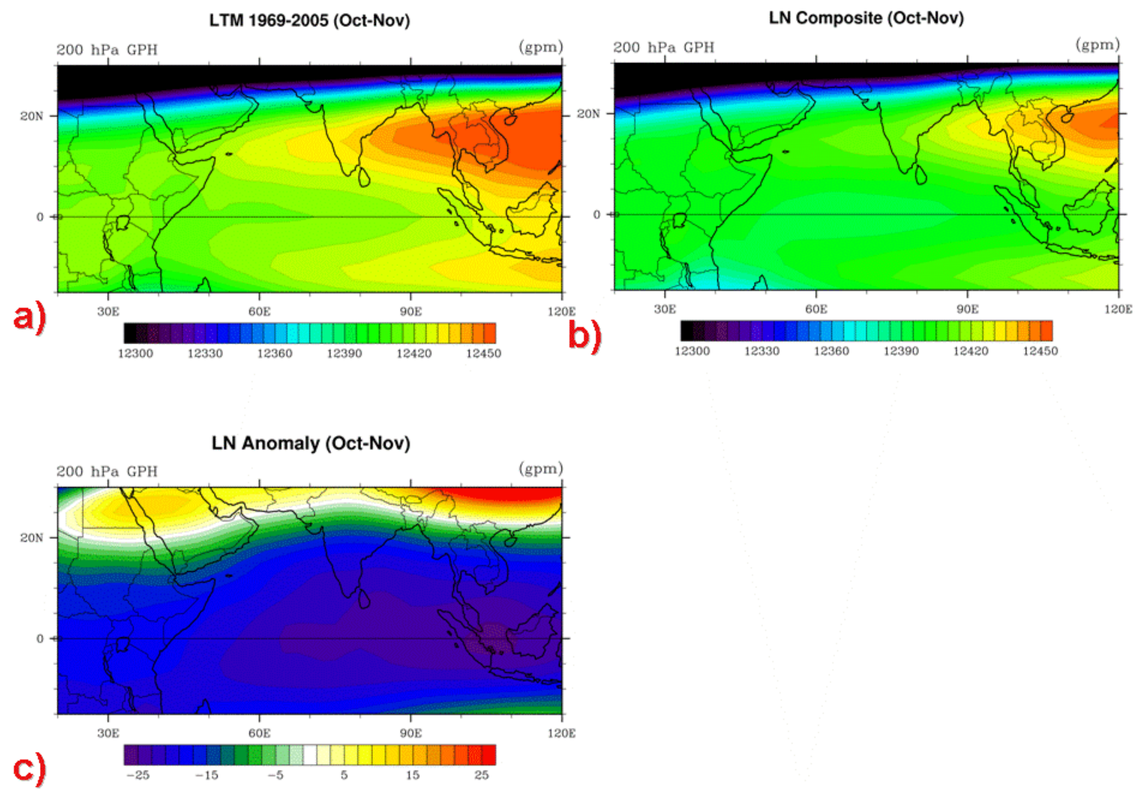

Figure 40. 200 hPa geopotential heights for: a) LTM; b) composite of five strongest LN events; c) composite anomaly of five strongest LN events.

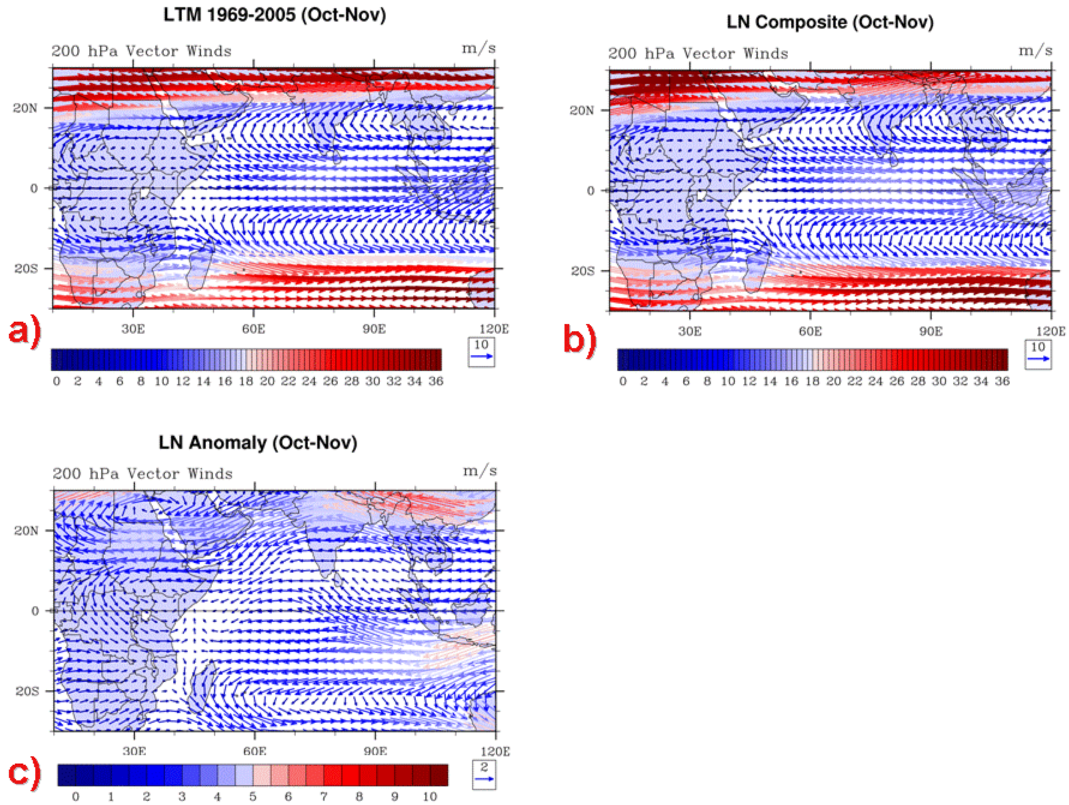

Figure 41. 200 hPa vector winds for: a) LTM; b) composite of five strongest LN events; c) composite anomaly of five strongest LN events.

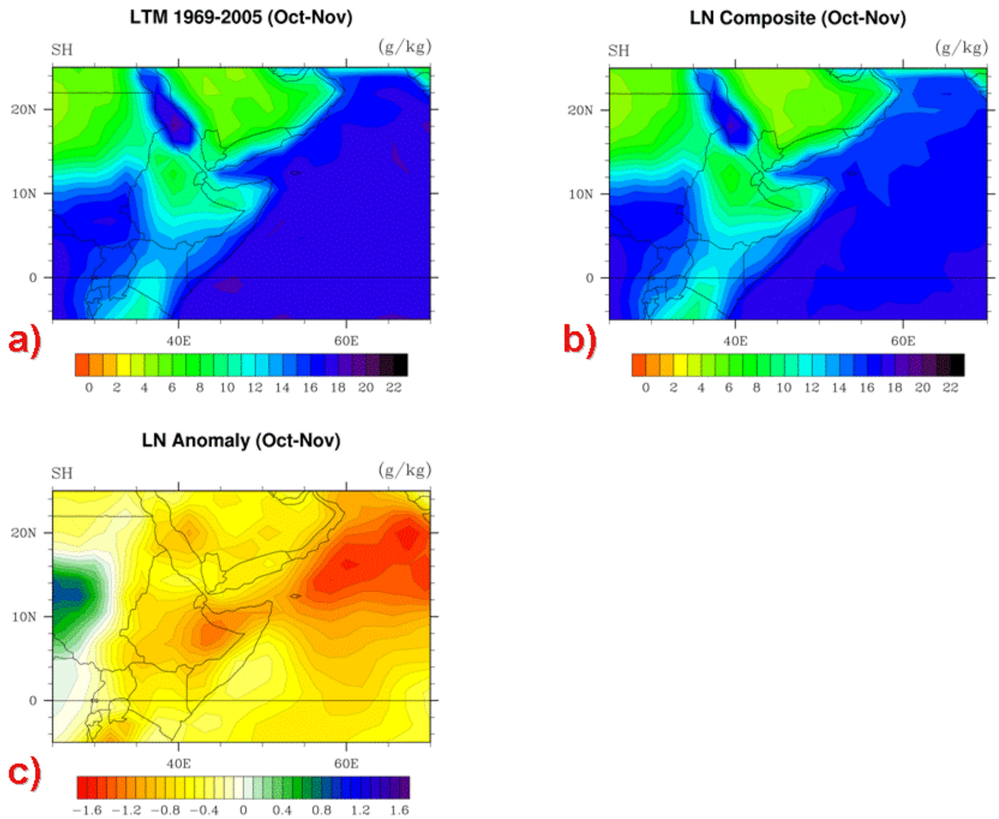

Figure 42. 850 hPa specific humidity for: a) LTM; b) composite of five strongest LN events; c) composite anomaly of five strongest LN events.

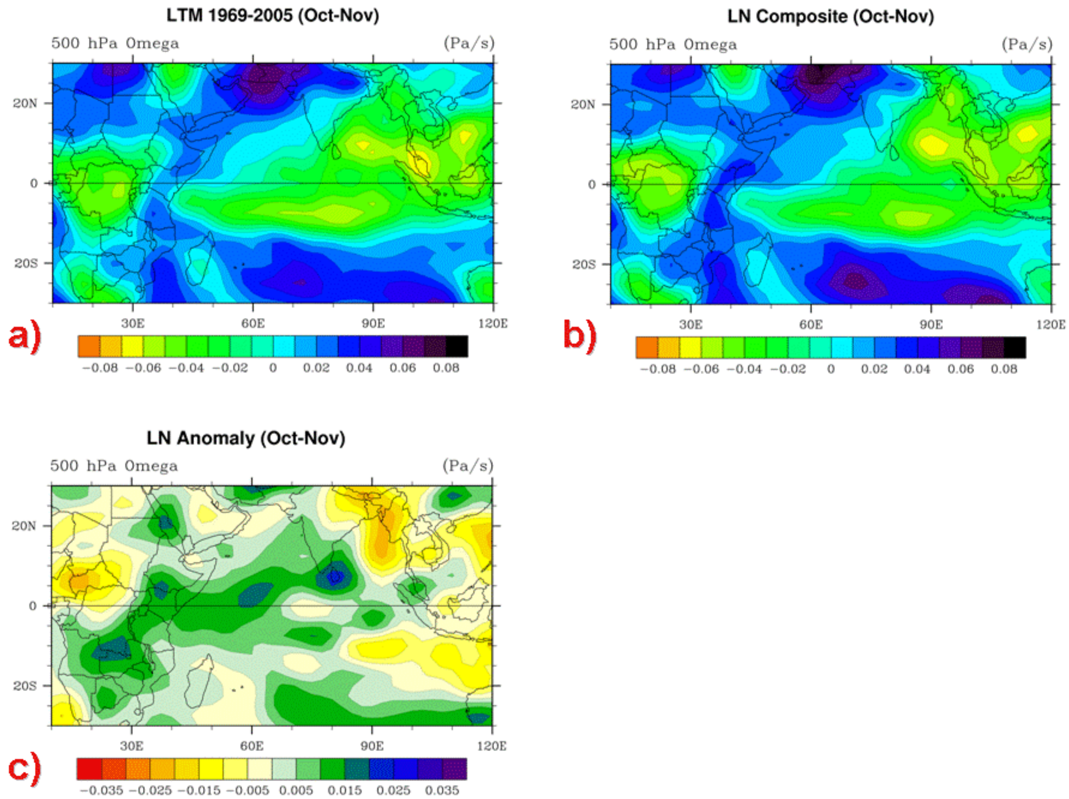

Figure 43. 500 hPa vertical velocity for: a) LTM b) composite of five strongest LN events c) composite anomaly of five strongest LN events

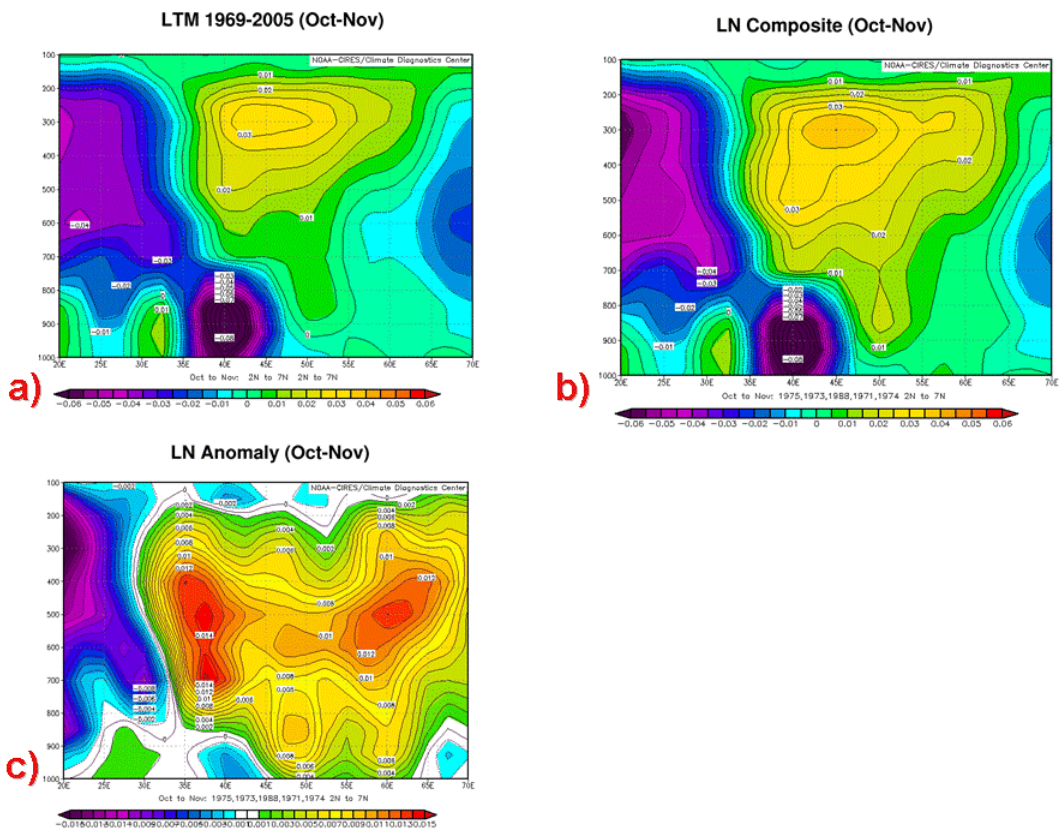

Figure 44. Omega vertical cross-section: for a) LTM; b) composite of five strongest LN events; c) composite anomaly of five strongest LN events.

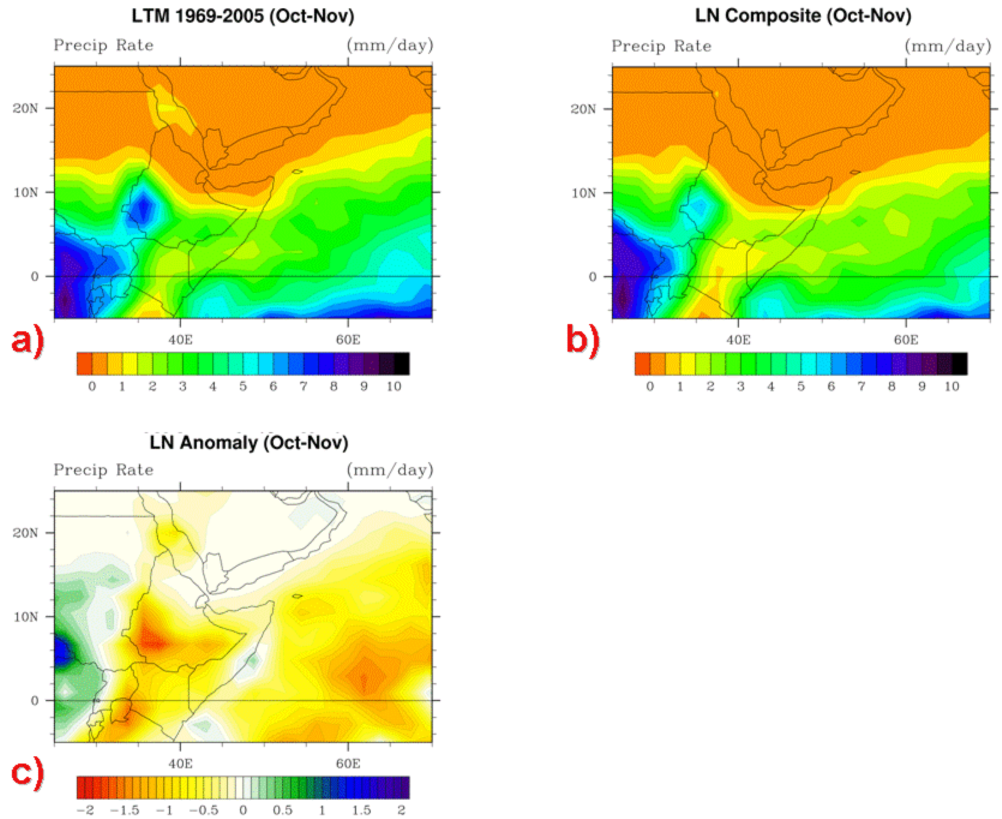

Figure 45. Precipitation rate for: a) LTM; b) composite of five strongest LN events; c) composite anomaly of five strongest LN events.

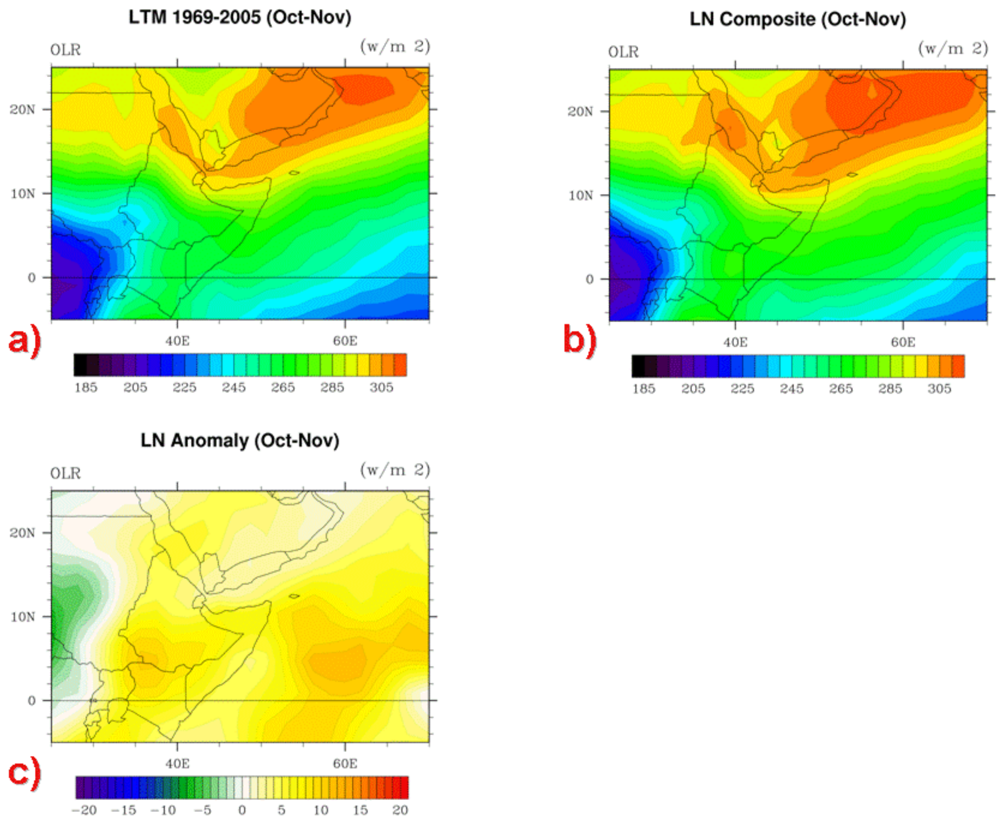

Figure 46. OLR for: a) LTM; b) composite of five strongest LN events; c) composite anomaly of five strongest LN events.

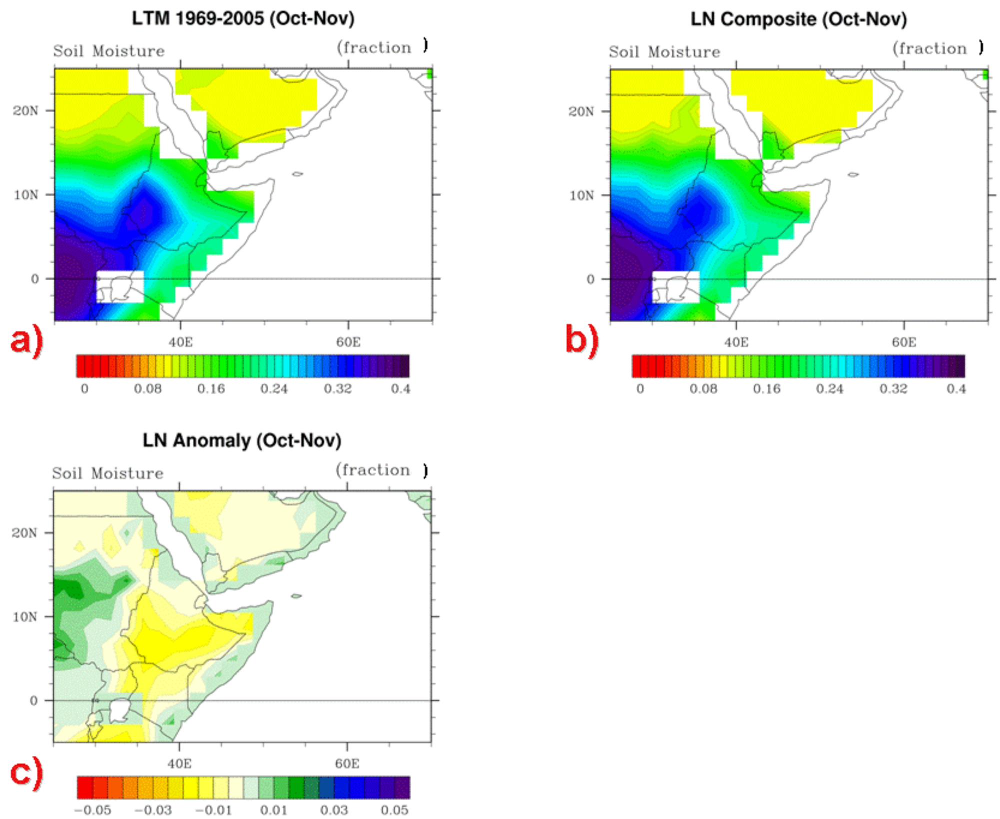

Figure 47. Volumetric soil moisture from the surface to a depth of 10 cm. for: a) LTM; b) composite of five strongest LN events; c) composite anomaly of five strongest LN events. Volumetric soil moisture is the percent water content per unit volume of soil.

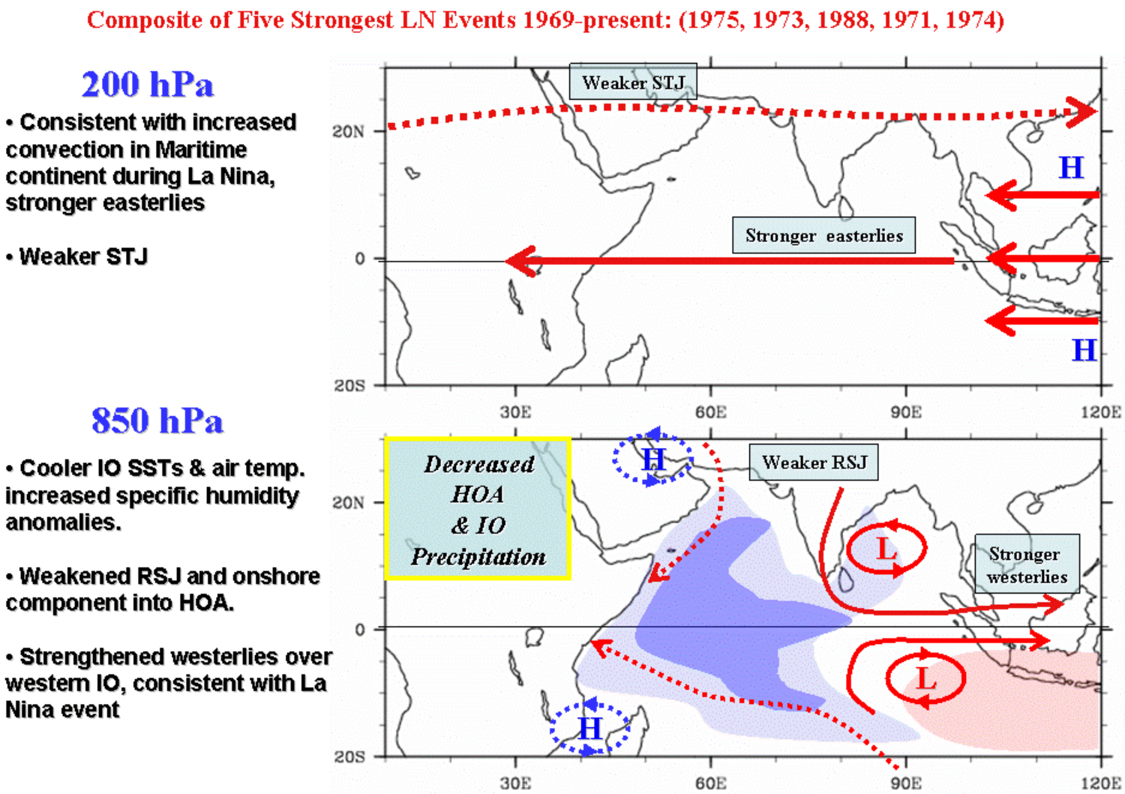

Figure 48. Schematic representation of anomalies associated with strong LN events at a) 200 hPa and b) 850 hPa. STJ = subtropical jet. RSJ = reverse Somali jet. IO = Indian Ocean.

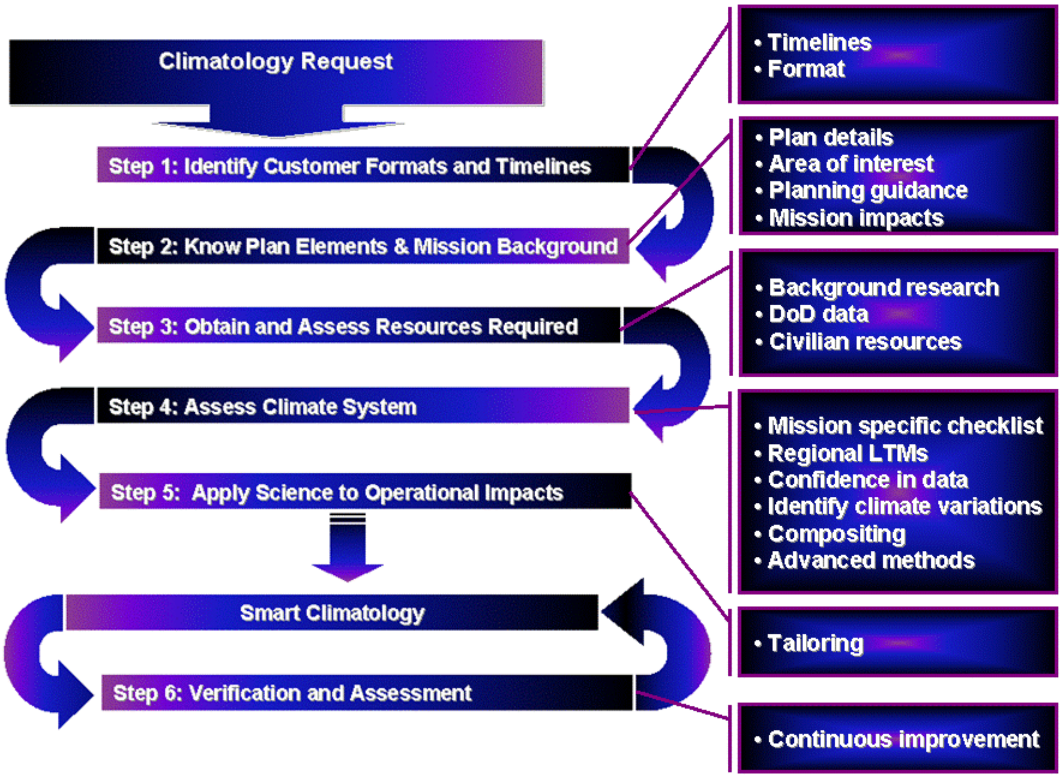

Figure 49. Flow chart depicting six-step smart climatology process.

Smart Military Climatology Checklist

- ◘ **Step 1: Identify Customer Formats and Timelines**
  - *Determine mission and delivery timelines*
  - *Ascertain required format*
- ◘ **Step 2: Know Plan Elements and Mission Background**
  - *Learn details of operation climate data will support*
  - *Determine area of interest*
  - *Review joint planning guidance*
  - *Research service-specific planning guidance*
  - *Learn mission impacts*
- ◘ **Step 3: Obtain and Assess Data and Resources Required**
  - *Conduct background research*
  - *Determine data DoD centers can provide*
  - *Research civilian organization resources*
- ◘ **Step 4: Assess Climate System**
  - *Build mission-specific checklist*
  - *Determine regional LTM climatology*
  - *Determine confidence in the LTM information*
  - *Identify relevant climate variations for the time of operations*
  - *Compositing*
  - *Consider more advanced statistical and dynamical methods*
- ◘ **Step 5: Apply the Science to Operational Impacts**
- ◘ **Step 6: Verification and Assessment**

Figure 50. Checklist for smart climatology process.

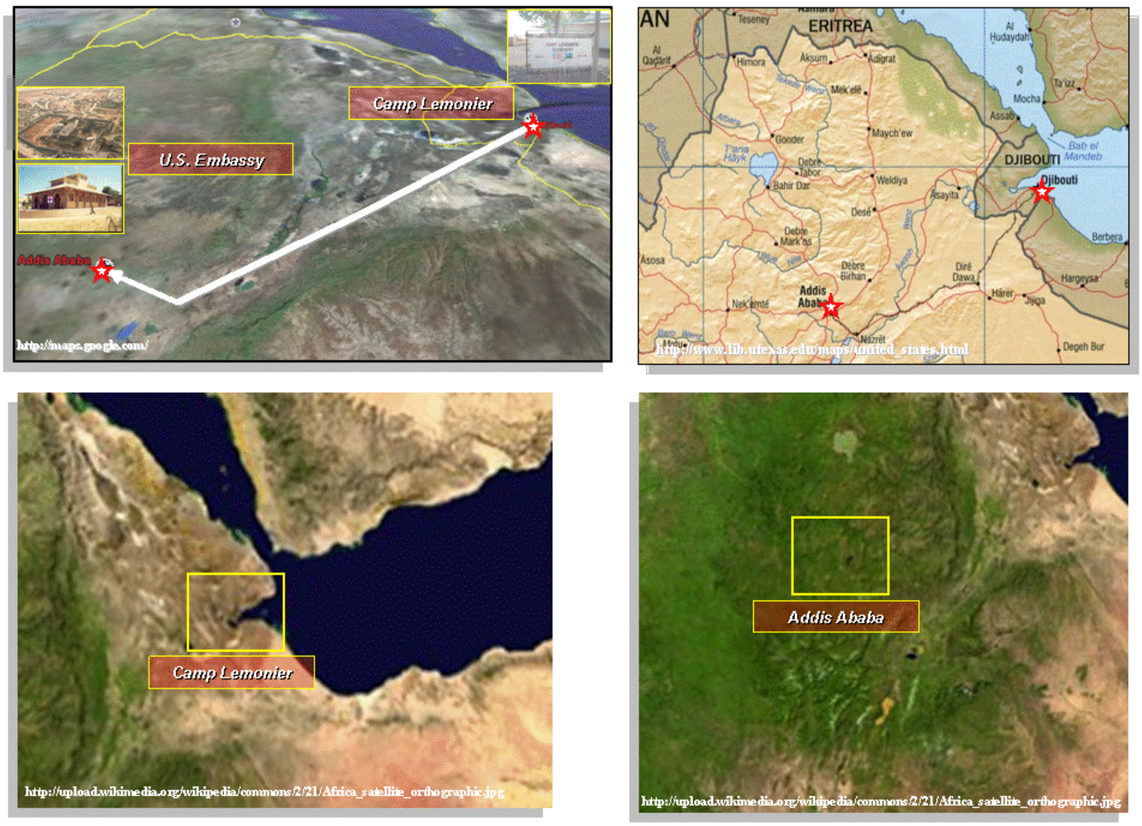

Figure 51. Areas of operations for notional, non-combatant evacuation operation (NEO) scenario occurring in the HOA region during October-November, concurrent with a strong EN event. Forces operating out of Camp Lemonier, Djibouti are tasked to evacuate U.S. embassy personnel from Addis Ababa, Ethiopia.

Mission	Favorable	Marginal	Unfavorable
C-17A Globemaster III	Ceiling > 1000' Vis > 5 nm Light icing Light FL turbulence	Ceiling 200'-500' Vis >0.5-3 nm Moderate Icing Moderate FL turbulence	Ceiling <200' Vis <0.5 nm Severe Icing Severe FL turbulence
HH-60G Pave Hawk	Ceiling > 500' Vis > 1600m	Ceiling 300'-500' Vis >1000 – 2000m Light turbulence/icing	Ceiling <300' Vis > 800m Moderate turbulence/icing
RQ1B Predator	Ceiling > 2000' Vis > 4800m Winds < 20 kts Crosswind < 10 kts No Precipitation Cloud cover < 30% No icing or turbulence Temp >-19C at FL180	Ceiling 800-2000' Vis 3200-4800m Winds < 20-30 kts Crosswind 10-15 kts Light Precipitation Cloud cover 30-50% Light Icing Light-moderate turbulence Temp <-19C below 18,000'	Ceiling < 008 Vis < 3200m Winds >30 kts Crosswind > 15 kts Heavy Precipitation Cloud cover > 50% Moderate icing/turbulence Temp <-19C below FL130 Freezing Precipitation
Satellite Reconnaissance	Clouds < 45% Sfc. vis. > 2000m	Clouds 45-55% 1000m < Sfc. vis. < 2000m	Clouds <55% Sfc. vis. > 020M
Trafficability	Ground Dry: Rain < .1"/hour Vis > 3200m Ceiling > 3000' Winds < 20 kts	Ground Moist: < 1" rain in 12 hours or > .1"/hour Vis >010-030m 20 kts<wind<30 kts	Ground Wet: > 2" rain in 12 hours or > .5"/hour Vis <010m Temp. >90 or <32F Wind > 30 kts Illumination <10Fcand.
Personnel	20F<Temp<85F Light precipitation	Temp -15F to 20F Moderate precipitation	Temp >95 or <-15 Heavy precipitation

Figure 52. Impacts table for notional NEO scenario. Impacts criteria from JP 3-59 (From: Joint Staff, 1999).

Operation	Operational Considerations	Climatological Features To Assess
Air Operations - C17A Globemaster III - HH-60G Pave Hawk	Cloud cover & visibility restrictions can hamper the full spectrum of air operations from launch to conducting the mission to recovery of the airframe. Also consider convective activity, winds, icing, turbulence.	Oct-Nov is the "short rains" season, so precipitation is expected. Already know there has been flooding. Analyze all moisture products such as specific humidity, precip and relative humidity, plus outgoing longwave radiation (for persistent cloudiness and convection). Also closely monitor wind products.
ISR - UAV (RQ1 Predator) - Satellite Collections	All air operations limitations apply, but are in general more restrictive due to the nature of the platforms (lower limits, mechanical issues). Remember to check crosswinds at operating location!	All features investigated above. Winds very important (cross, out of limits, etc.) very important to important for Predator launch and recovery.
Ground Operations - Trafficability - Personnel	Personnel comfort issues will be more of a factor since civilians are involved...likely a high-interest issue. Civilian vehicles used, and roads are poor, so precipitation will be a major consideration as well.	Consider moisture products measured above. NEO teams will also ask questions about wet-bulb globe, so be prepared to supply information so they can compute.

Figure 53. Mission Specific Checklist for NEO scenario.

Air Operations	Horn of Africa (Oct - Nov) NEO		
	Typical Climate (Long Term Mean)	Tendency	
		Strong El Nino (EN)	Strong La Nina (LN)
C-17A Globemaster III	Clouds, Rain, Thunderstorms	Increased Clouds, Rain and Thunderstorms	Decreased Clouds, Rain, Thunderstorms
HH-60G Pave Hawk			

Typical: October–November is the "short rains" season in the Horn of Africa, characterized by extensive cloud decks and showers associated with thunderstorm activity. The assessment for both C-17A and rotary wing airlift operations is overall favorable with moderate impacts due to thunderstorm activity. Assessment improves to favorable by late October with the end of the short rains. Favorable for Camp Lemonier.

El Nino: Strong El Nino events tend to increase showers, cloud cover and thunderstorm activity during October-November. All air operations are assessed moderate to occasionally unfavorable, especially during afternoons. Assessment improves to favorable by mid-November. No significant impacts at Camp Lemonier.

La Nina: Strong La Nina events tend to suppress showers, cloud cover and thunderstorm activity during Oct-Nov. Air operations impacts improved over typical years. No significant impacts at Camp Lemonier.

Favorable	Moderate	Unfavorable	No Change

Figure 54. Prototype air operations tendency chart for notional NEO scenario in the HOA. Impacts criteria used for the assessment derived from Joint Staff (1999).

Intelligence, Surveillance and Reconnaissance (ISR)	Horn of Africa (Oct - Nov) NEO		
	Typical Climate (Long Term Mean)	Tendency	
		Strong El Nino (EN)	Strong La Nina (LN)
RQ1B Predator	Clouds, Rain, Thunderstorms	Increased Clouds, Rain, Thunderstorms	Decreased Clouds, Rain, Thunderstorms
Satellite Collections	Clouds, Rain, Thunderstorms	Increased Clouds, Rain, Thunderstorms	Decreased Clouds, Rain, Thunderstorms

Typical: October–November is the "short rains" season in the Horn of Africa, characterized by extensive cloud decks and showers associated with thunderstorm activity. Moderate impacts to Predator collections activities due to cloud cover and thunderstorm hazards. Moderate impacts to satellite collections activities due to cloud cover. Predator launch and recovery out of Camp Lemonier is assessed favorable, with occasional moderate impacts due to high afternoon temperatures.

El Nino: Strong El Nino events tend to increase showers, cloud cover and thunderstorm activity during October-November. Predator mission impacts tend to moderate-occasionally unfavorable. Satellite collections are assessed unfavorable-occasionally moderate, especially during periods of increased thunderstorm activity.

La Nina: Strong La Nina events tend to suppress showers, cloud cover and thunderstorm activity during Oct-Nov. ISR operations tend toward improvement over typical years, with mostly favorable-occasionally moderate impacts.

Favorable	Moderate	Unfavorable	No Change

Figure 55. Prototype ISR tendency chart for notional NEO scenario in the HOA. Impacts criteria used for the assessment derived from Joint Staff (1999).

Ground Operations	Horn of Africa (Oct - Nov) NEO		
	Typical Climate (Long Term Mean)	Tendency	
		Strong El Nino (EN)	Strong La Nina (LN)
Trafficability	Clouds, Rain, Thunderstorms	Increased Clouds, Rain, Thunderstorms	Decreased Clouds, Rain, Thunderstorms
Personnel	Clouds, Rain, Thunderstorms	Increased Clouds, Rain, Thunderstorms	Decreased Clouds, Rain, Thunderstorms

Typical: October–November is the "short rains" season in the Horn of Africa, characterized by extensive cloud decks and showers associated with thunderstorm activity. For typical years, trafficability is assessed moderate on unimproved roads, favorable elsewhere. Personnel assessed favorable occasionally moderate due to rain and thunderstorms.

El Nino: Strong El Nino events tend to increase showers, cloud cover and thunderstorm activity during October-November. Trafficability will tend towards moderate overall, with unfavorable impacts on unimproved roads. Personnel impacts tend towards moderate due to rainfall.

La Nina: Strong La Nina events tend to suppress showers, cloud cover and thunderstorm activity during Oct-Nov. Trafficability and Personnel impacts favorable.

Favorable	Moderate	Unfavorable	No Change

Figure 56. Prototype ground operations tendency chart for notional NEO scenario in the HOA. Impacts criteria used for the assessment derived from Joint Staff (1999).

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